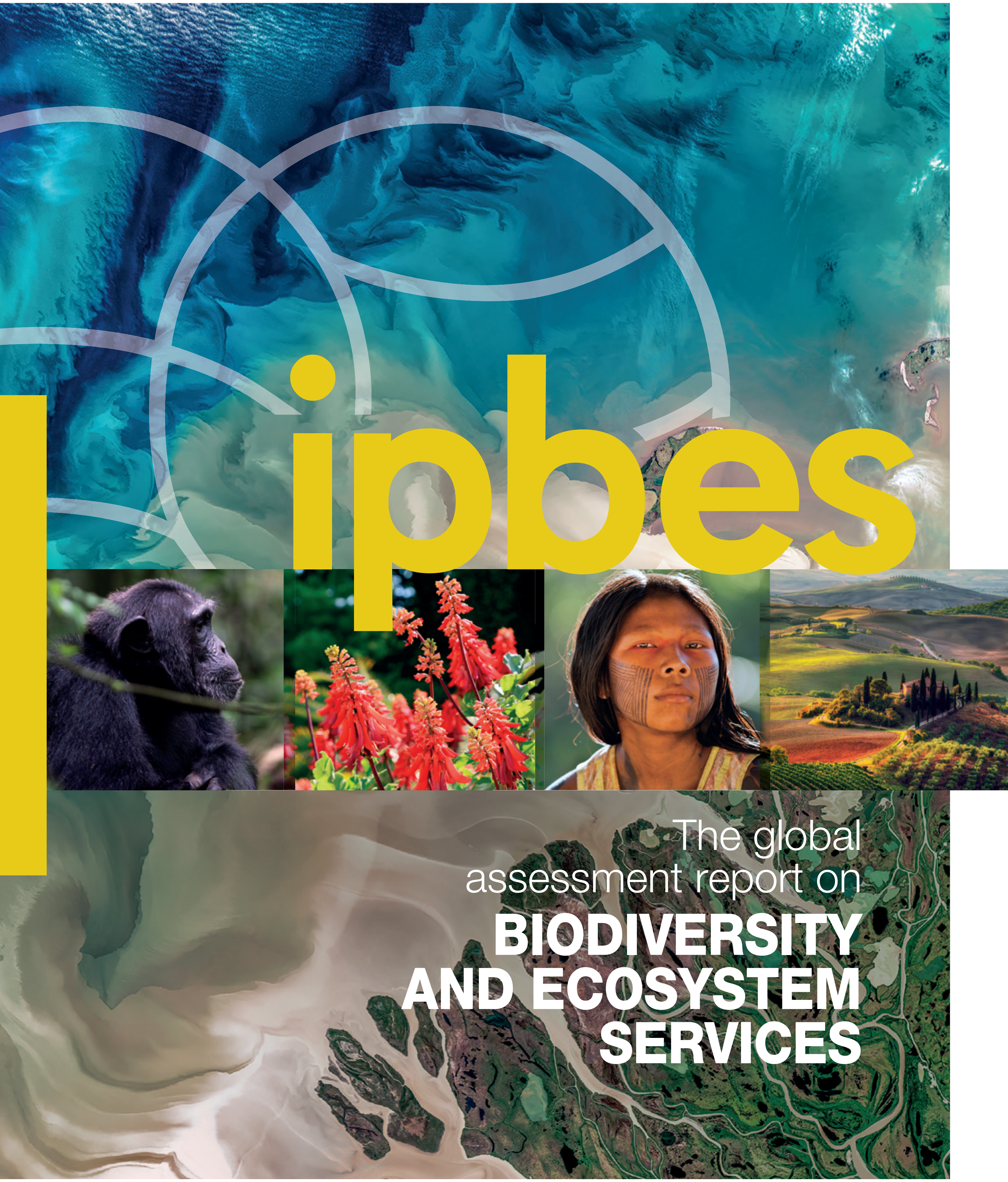

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The global assessment report on BIODIVERSITY AND ECOSYSTEM SERVICES

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GLOBAL ASSESSMENT REPORT OF THE INTERGOVERNMENTAL SCIENCE-POLICY PLATFORM ON BIODIVERSITY AND ECOSYSTEM SERVICES

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The global assessment report on BIODIVERSITY AND ECOSYSTEM SERVICES

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FOREWORD

A key objective of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) is to provide Governments, the private sector and civil society with scientifically credible and independent up-to-date assessments of available knowledge for better evidence-informed policy decisions and action at the local, national, regional and global levels.

This Global Assessment of Biodiversity and Ecosystem Services has been carried out by about 150 selected experts from all regions of the world, including 16 early career fellows, assisted by 350 contributing authors. More than 15,000 scientific publications were analyzed as well as a substantive body of indigenous and local knowledge. Its chapters were accepted, and its summary for policymakers was approved, by the more than 130 Governments that constitute the Members of IPBES, at the seventh session of the IPBES Plenary (29th April to 4th May, 2019), hosted by France at UNESCO in Paris.

This report represents a critical assessment, the first in almost 15 years (since the release of the Millennium Ecosystem Assessment in 2005) and the first ever carried out by an intergovernmental body, of the status and trends of the natural world, the social implications of these trends, their direct and indirect causes, and, importantly, the actions that can still be taken to ensure a better future for all. These complex links have been assessed using a simple, yet very inclusive framework that should resonate with a wide range of stakeholders, since it recognizes diverse world views, values and knowledge systems.

The concept of nature's contributions to people, which is discussed in detail in chapter 1, embraces a wide range of descriptions of human-nature interactions, including through the concept of ecosystem services and other descriptions, which range from strongly utilitarian to strongly relational. The concept of nature's contribution to people was developed to embrace a fuller and more symmetric consideration of diverse stakeholders and world views, and a richer evidence base for action, i.e., the knowledge base offered by the natural and social sciences, the humanities, and the knowledge of practitioners and indigenous peoples and local communities. The reporting system for nature's contributions to people has a gradient of complementary and overlapping approaches, ranging from a generalizing to a context-specific perspective. The generalizing perspective is analytical in purpose and is organized into eighteen categories of material, non-material and regulating contributions. The context-specific perspective is typical of indigenous and local knowledge systems, where

IPBES is an independent intergovernmental body comprising over 130 member Governments. Established by Governments in 2012, IPBES provides policymakers with objective scientific assessments about the state of knowledge regarding the planet's biodiversity, ecosystems and the contributions they make to people, as well as options and actions to protect and sustainably use these vital natural assets.

The IPBES Global Assessment of Biodiversity and Ecosystem Services represents the landmark product of the first work programme of IPBES (2014-2018). The Global Assessment was initiated following a decision from the IPBES Plenary at its fourth session (IPBES 4, Kuala Lumpur, 2016), and considered by the IPBES Plenary at its seventh session (IPBES 7, Paris, 2019). It is composed of a summary for policymakers, which was approved at IPBES 7, and six chapters, which were accepted at IPBES 7.

knowledge production does not typically seek to explicitly extend or validate itself beyond specific geographic and cultural contexts. In this way, the nature's contributions to people approach (or the IPBES approach) builds on the existing approaches, descriptors and metrics used by different communities of practice in the search for understanding and solutions.

In the last 10-15 years, since the Millennium Ecosystem Assessment, there has been a significant increase in our understanding of biodiversity and ecosystems, as well as their importance to the quality of life of every person. There is also greater understanding now about which policies, practices, technologies and behaviors can best lead to the conservation and sustainable use of biodiversity and the achievement of many of the Sustainable Development Goals, the Aichi Biodiversity Targets and the Paris Agreement on Climate Change. However, biodiversity is still being lost, ecosystems are still being degraded and many of nature's contributions to people are being compromised.

The Assessment is critical today because evidence has accumulated that the multiple threats to biodiversity have intensified since previous reports, and that the sustainable use of nature will be vital for adapting to and mitigating dangerous anthropogenic interference with the climate system, as well as for achieving many of our most important development goals.

The findings of this Assessment focus on the global scale, spanning the period from the 1970s to 2050. They are based on an unprecedented collection of evidence, integrating natural and social science perspectives, a range of knowledge systems and multiple dimensions of value. This is the first global-level assessment to systematically consider evidence about the contributions of indigenous and local knowledge and practices, and issues concerning Indigenous Peoples and Local Communities. All these features result in a more holistic assessment of indirect drivers as root causes of changes in nature and the associated risks to the quality of life of all people.

As the Chair and the Executive Secretary of IPBES, we wish to recognize the excellent and dedicated work of the co-chairs, Professors Sandra Díaz (Argentina), Eduardo S. Brondízio (Brazil and USA), and Josef Settele (Germany) and of all the coordinating lead authors, lead authors, review editors, fellows, contributing authors and reviewers, and to warmly thank them for their commitment, and for contributing their time freely to this important report. We would also like to thank Hien Ngo and Maximilien Guèze from the technical support unit located at the IPBES secretariat in Bonn, Germany, because this report would not have been possible without their extraordinary dedication. Our thanks also go the current and former members of the Multidisciplinary Expert Panel (MEP) and of the Bureau who provided guidance as part of the management committee for this report, and to members of other technical support units within the IPBES secretariat, who have supported the production of this report. We would also like to thank all Governments and other institutions that provided financial and in-kind support for the preparation of this assessment.

The IPBES Global Assessment of Biodiversity and Ecosystem Services, together with the four IPBES regional assessments of Biodiversity and Ecosystem Services, and the two thematic Assessments of Pollination, Pollinators and Food Production, and of Land Degradation and Restoration, form an impressive corpus of knowledge to make better-informed decisions regarding the conservation and sustainable use of biodiversity. The IPBES Global Assessment is expected to be an important evidence base for the assessment of progress towards the achievement of the Aichi Biodiversity Targets in the fifth edition of the Global Biodiversity Outlook and to play a major role in the consideration of the post 2020 biodiversity framework by the 15th Conference of the Parties to the Convention on Biological Diversity, in October 2020. It is also expected to inform implementation of the 2030 Agenda for Sustainable Development, the Sustainable Development Goals and the Paris Agreement on Climate Change. It is our sincere hope that the IPBES Global Assessment will continue to place biodiversity at the top of the global political agenda, with similar priority to that accorded to climate change. The process leading to COP 15 offers this opportunity.

Sir Robert T. Watson
Chair of IPBES from 2016 to 2019

Anne Larigauderie
Executive Secretary of IPBES

STATEMENTS FROM KEY PARTNERS

Nature makes human development possible but our relentless demand for the earth's resources is accelerating extinction rates and devastating the world's ecosystems. UN Environment is proud to support the Global Assessment Report produced by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services because it highlights the critical need to integrate biodiversity considerations in global decision-making on any sector or challenge, whether its water or agriculture, infrastructure or business.

Joyce Masuya

Acting Executive Director,
United Nations Environment Programme (UNEP)

This essential report reminds each of us of the obvious truth: the present generations have the responsibility to bequeath to future generations a planet that is not irreversibly damaged by human activity. Our local, indigenous and scientific knowledge are proving that we have solutions and so no more excuses: we must live on earth differently. UNESCO is committed to promoting respect of the living and of its diversity, ecological solidarity with other living species, and to establish new, equitable and global links of partnership and intragenerational solidarity, for the perpetuation of humankind.

Audrey Azoulay

Director-General,
United Nations Educational, Scientific and Cultural Organization (UNESCO)

The *Global assessment of biodiversity and ecosystem services* adds a major element to the body of evidence for the importance of biodiversity to efforts to achieve the Zero Hunger objective and meet the Sustainable Development Goals. Together, assessments undertaken by IPBES, FAO, CBD and other organizations point to the urgent need for action to better conserve and sustainably use biodiversity and to the importance of cross-sectoral and multidisciplinary collaboration among decision-makers and other stakeholders at all levels.

José Graziano da Silva

Director-General,
Food and Agriculture Organization of the United Nations (FAO)

Across cultures, humans inherently value nature. The magic of seeing fireflies flickering long into the night is immense. We draw energy and nutrients from nature. We find sources of food, medicine, livelihoods and innovation in nature. Our well-being fundamentally depends on nature. Our efforts to conserve biodiversity and ecosystems must be underpinned by the best science that humanity can produce. This is why the scientific evidence compiled in this IPBES Global Assessment is so important. It will help us build a stronger foundation for shaping the post 2020 global biodiversity framework: the 'New Deal for Nature and People'; and for achieving the SDGs.

Achim Steiner

Administrator,
United Nations Development Programme (UNDP)

The IPBES' 2019 Global Assessment Report on Biodiversity and Ecosystem Services comes at a critical time for the planet and all its peoples. The report's findings — and the years of diligent work by the many scientists who contributed— will offer a comprehensive view of the current conditions of global biodiversity. Healthy biodiversity is the essential infrastructure that supports all forms of life on earth, including human life. It also provides nature-based solutions on many of the most critical environmental, economic, and social challenges that we face as human society, including climate change, sustainable development, health, and water and food security. We are currently in the midst of preparing for the 2020 UN Biodiversity Conference, in China, which will mark the close of the Aichi Biodiversity Targets and set the course for a post 2020 ecologically focused sustainable development pathway to deliver multiple benefits for people, the planet and our global economy. The IPBES report will serve as a fundamental baseline of where we are and where we need to go as a global community to inspire humanity to reach the 2050 Vision of the UN Biodiversity Convention "Living in harmony with nature". I want to extend my thanks and congratulations to the IPBES community for their hard work, immense contributions and continued partnership.

Dr. Cristiana Paşca Palmer

Executive Secretary,
Convention on Biological Diversity (CBD)

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The co-chairs of the IPBES Global Assessment Report of Biodiversity and Ecosystem Services wish to thank the people and institutions that helped to make the Report possible.

We are first indebted to the hundreds of experts in biophysical and social sciences, policymakers and practitioners, as well as representatives of Indigenous Peoples and Local Communities, who generously contributed their time and knowledge, as lead authors, chapter scientists, resource person, and/or review editors (listed below), and to all contributing authors. We are fortunate to have had the opportunity to work with such an engaged, collegial and superb group of authors.

We are grateful to the members of the IPBES secretariat, particularly Executive Secretary Anne Larigauderie, the IPBES Chair (Robert Watson), representatives of member States, the Multidisciplinary Expert Panel and Bureau and other resource persons for their dedication, strategic vision, constructive comments and continued advice. The Global Assessment would not have been possible without the titanic effort of its technical support unit (Hien T. Ngo and Maximilien Guèze) during the whole process, including the long and challenging seventh session of the IPBES Plenary (#IPBES7), which resulted in the approval of this report and its summary for policymakers. In addition, we are thankful for the support of several IPBES technical support units, and their host institutions at different stages of the process: Knowledge and data technical support unit (NIE, Republic of Korea), indigenous and local knowledge technical support unit (UNESCO), scenarios and models technical support unit (PBL, Netherlands), and the capacity building technical support unit (NEA, Norway). We also thank the data visualization specialist and the graphic designer for their skillful work. We would like to thank the IPBES communications team, for their outstanding work communicating the main messages to the general public.

We are also grateful to all supportive Governments but in particular the Governments of Germany, South Africa, Norway, the United Kingdom, France, and the Netherlands as well as to the Córdoba Province (Argentina), who generously hosted our chapter and/or author meetings. The co-chairs would especially like to acknowledge the support of their home institutions and governments: the Helmholtz Centre for Environmental Research – UFZ (Germany), iDiv (the German Centre for Integrative Biodiversity Research), Universidad Nacional de Córdoba and CONICET (Argentina), and Indiana University-Bloomington (USA). Finally, our gratitude goes to the Government of France for hosting #IPBES 7 and to UNESCO for providing the venue and support. The dedication and contributions of all of the governments, organizations and people above made the Global Assessment possible and impactful and for that we are deeply indebted and appreciative.

Eduardo S. Brondízio, Josef Settele, Sandra Díaz
Co-Chairs

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This IPBES Global Assessment of Biodiversity and Ecosystem Services is dedicated to the memory of Georgina Mace.

Georgina was a Fellow of the Royal Society and received during her rich career an impressive list of honors and prizes worldwide. She strongly believed in the power of science to inform policymaking and, following her involvement in the Millennium Ecosystem Assessment, played, as Chair of the Scientific Committee of DIVERSITAS, a key role in supporting the process that led in 2012 to the establishment of IPBES.

Georgina followed the work of IPBES very closely and, for this IPBES Global Assessment, played the critical role of overall review editor. She will be greatly missed and remembered for her lifelong commitment to biodiversity, to science and to science-policy, for being a loyal friend to so many, and for her vision, style, leadership, modesty and sense of humour.

The global assessment report on BIODIVERSITY AND ECOSYSTEM SERVICES

SUMMARY FOR POLICYMAKERS

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KEY MESSAGES

KEY MESSAGES

A. Nature and its vital contributions to people, which together embody biodiversity and ecosystem functions and services, are deteriorating worldwide.

Nature embodies different concepts for different people, including biodiversity, ecosystems, Mother Earth, systems of life and other analogous concepts. Nature's contributions to people embody different concepts, such as ecosystem goods and services and nature's gifts. Both nature and nature's contributions to people are vital for human existence and good quality of life (human well-being, living in harmony with nature, living well in balance and harmony with Mother Earth, and other analogous concepts). While more food, energy and materials than ever before are now being supplied to people in most places, this is increasingly at the expense of nature's ability to provide such contributions in the future, and frequently undermines nature's many other contributions, which range from water quality regulation to sense of place. The biosphere, upon which humanity as a whole depends, is being altered to an unparalleled degree across all spatial scales. Biodiversity – the diversity within species, between species and of ecosystems – is declining faster than at any time in human history.

A1 Nature is essential for human existence and good quality of life. Most of nature's contributions to people are not fully replaceable, and some are irreplaceable. Nature plays a critical role in providing food and feed, energy, medicines and genetic resources and a variety of materials fundamental for people's physical well-being and for maintaining culture. For example, more than 2 billion people rely on wood fuel to meet their primary energy needs, an estimated 4 billion people rely primarily on natural medicines for their health care and some 70 per cent of drugs used for cancer are natural or are synthetic products inspired by nature. Nature, through its ecological and evolutionary processes, sustains the quality of the air, fresh water and soils on which humanity depends, distributes fresh water, regulates the climate, provides pollination and pest control and reduces the impact of natural hazards. For example, more than 75 per cent of global food crop types, including fruits and vegetables and some of the most important cash crops, such as coffee, cocoa and almonds, rely on animal pollination. Marine and terrestrial ecosystems are the sole sinks for anthropogenic carbon emissions, with a gross sequestration of 5.6 gigatons of carbon per year (the equivalent of some 60 per cent of global anthropogenic emissions). Nature underpins all dimensions of human health and contributes to non-material aspects of quality of life – inspiration and learning, physical and psychological experiences, and supporting identities – that are central to quality of life and cultural integrity, even if their aggregated value is difficult to quantify. Most of nature's contributions are co-produced with people, but while anthropogenic assets – knowledge and institutions, technology infrastructure and financial capital – can enhance or partially replace some of those contributions, some are irreplaceable. The diversity of nature maintains humanity's ability to choose alternatives in the face of an uncertain future.

A2 Nature's contributions to people are often distributed unequally across space and time and among different segments of society. There are often trade-offs in the production and use of nature's contributions. Benefits and burdens associated with co-production and use of nature's contributions are distributed and experienced differently among social groups, countries and regions. Giving priority to one of nature's contributions to people, such as food production, can result in ecological changes that reduce other contributions. Some of these changes may benefit some people at the expense of others, particularly the most vulnerable, as may changes in technological and institutional arrangements. For example, although food production today is sufficient to satisfy global needs, approximately 11 per cent of the world's population is undernourished, and diet-related disease drives 20 per cent of premature mortality, related both to undernourishment and to obesity. The great expansion in the production of food, feed, fibre and bioenergy has occurred at the cost of many other contributions of nature to quality of life, including regulation of air and water quality, climate regulation and habitat provision. Synergies also exist, such as sustainable agricultural practices that enhance soil quality, thereby improving productivity and other ecosystem functions and services, such as carbon sequestration and water quality regulation.





A3 Since 1970, trends in agricultural production, fish harvest, bioenergy production and harvest of materials have increased, but 14 of the 18 categories of contributions of nature that were assessed, mostly regulating and non-material contributions, have declined. The value of agricultural crop production ($2.6 trillion in 2016) has increased approximately threefold since 1970 and raw timber harvest has increased by 45 per cent, reaching some 4 billion cubic metres in 2017, with the forestry industry providing about 13.2 million jobs. However, indicators of regulating contributions, such as soil organic carbon and pollinator diversity, have declined, indicating that gains in material contributions are often not sustainable. Currently, land degradation has reduced productivity in 23 per cent of the global terrestrial area, and between $235 billion and $577 billion[3] in annual global crop output is at risk as a result of pollinator loss. Moreover, loss of coastal habitats and coral reefs reduces coastal protection, which increases the risk from floods and hurricanes to life and property for the 100 million to 300 million people living within coastal 100-year flood zones.

A4 Nature across most of the globe has now been significantly altered by multiple human drivers, with the great majority of indicators of ecosystems and biodiversity showing rapid decline. Seventy-five per cent of the land surface is significantly altered, 66 per cent of the ocean area is experiencing increasing cumulative impacts, and over 85 per cent of wetlands (area) has been lost. While the rate of forest loss has slowed globally since 2000, this is distributed unequally. Across much of the highly biodiverse tropics, 32 million hectares of primary or recovering forest were lost between 2010 and 2015. The extent of tropical and subtropical forests is increasing within some countries, and the global extent of temperate and boreal forests is increasing. A range of actions – from restoration of natural forest to planting of monocultures – contributes to these increases, but these actions have very different consequences for biodiversity and its contributions to people. Approximately half the live coral cover on coral reefs has been lost since the 1870s, with accelerating losses in recent decades due to climate change exacerbating other drivers. The average abundance of native species in most major terrestrial biomes has fallen by at least 20 per cent, potentially affecting ecosystem processes and hence nature's contributions to people; this decline has mostly taken place since 1900 and may be accelerating. In areas of high endemism, native biodiversity has often been severely impacted by invasive alien species. Population sizes of wild vertebrate species have tended to decline over the last 50 years on land, in freshwater and in the sea. Global trends in insect populations are not known but rapid declines have been well documented in some places.

A5 Human actions threaten more species with global extinction now than ever before. An average of around 25 per cent of species in assessed animal and plant

3. Value adjusted to 2015 United States dollars, taking into account inflation only.

groups are threatened **(Figure SPM.3)**, suggesting that around 1 million species already face extinction, many within decades, unless action is taken to reduce the intensity of drivers of biodiversity loss. Without such action, there will be a further acceleration in the global rate of species extinction, which is already at least tens to hundreds of times higher than it has averaged over the past 10 million years **(Figure SPM.4)**.

A6 Globally, local varieties and breeds of domesticated plants and animals are disappearing. This loss of diversity, including genetic diversity, poses a serious risk to global food security by undermining the resilience of many agricultural systems to threats such as pests, pathogens and climate change. Fewer and fewer varieties and breeds of plants and animals are being cultivated, raised, traded and maintained around the world, despite many local efforts, which include those by indigenous peoples and local communities. By 2016, 559 of the 6,190 domesticated breeds of mammals used for food and agriculture (over 9 per cent) had become extinct and at least 1,000 more are threatened. In addition, many crop wild relatives that are important for long-term food security lack effective protection, and the conservation status of wild relatives of domesticated mammals and birds is worsening. Reductions in the diversity of cultivated crops, crop wild relatives and domesticated breeds mean that agroecosystems are less resilient against future climate change, pests and pathogens.

A7 Biological communities are becoming more similar to each other in both managed and unmanaged systems within and across regions. This human-caused process leads to losses of local biodiversity, including endemic species, ecosystem functions and nature's contributions to people.

A8 Human-induced changes are creating conditions for fast biological evolution – so rapid that its effects can be seen in only a few years or even more quickly. The consequences can be positive or negative for biodiversity and ecosystems, but can create uncertainty about the sustainability of species, ecosystem functions and the delivery of nature's contributions to people. Understanding and monitoring these biological evolutionary changes is as important for informed policy decisions as it is in cases of ecological change. Sustainable management strategies then can be designed to influence evolutionary trajectories so as to protect vulnerable species and reduce the impact of unwanted species (such as weeds, pests or pathogens). The widespread declines in geographic distribution and population sizes of many species make clear that, although evolutionary adaptation to human-caused drivers can be rapid, it has often not been sufficient to mitigate them fully.

B. Direct and indirect drivers of change have accelerated during the past 50 years.

The rate of global change in nature during the past 50 years is unprecedented in human history. The direct drivers of change in nature with the largest global impact have been (starting with those with most impact): changes in land and sea use; direct exploitation of organisms; climate change; pollution; and invasion of alien species. Those five direct drivers result from an array of underlying causes – the indirect drivers of change – which are in turn underpinned by societal values and behaviours that include production and consumption patterns, human population dynamics and trends, trade, technological innovations and local through global governance. The rate of change in the direct and indirect drivers differs among regions and countries.

B1 For terrestrial and freshwater ecosystems, land-use change has had the largest relative negative impact on nature since 1970, followed by the direct exploitation, in particular overexploitation, of animals, plants and other organisms, mainly via harvesting, logging, hunting and fishing. In marine ecosystems, direct exploitation of organisms (mainly fishing) has had the largest relative impact, followed by land-/sea-use change. Agricultural expansion is the most widespread form of land-use change, with over one third of the terrestrial land surface being used for cropping or animal husbandry. This expansion, alongside a doubling of urban area since 1992 and an unprecedented expansion of infrastructure linked to growing population and consumption, has come mostly at the expense of forests (largely old-growth tropical forests), wetlands and grasslands. In freshwater ecosystems, a series of combined threats that include land-use change, including water extraction, exploitation, pollution, climate change and invasive species, are prevalent. Human activities have had a large and widespread impact on the world's oceans. These include direct exploitation, in particular overexploitation, of fish, shellfish and other organisms, land- and sea-based pollution, including from river networks, and land-/sea-use change, including coastal development for infrastructure and aquaculture.



B2 Climate change is a direct driver that is increasingly exacerbating the impact of other drivers on nature and human well-being. Humans are estimated to have caused an observed warming of approximately 1.0°C by 2017 relative to pre-industrial levels, with average temperatures over the past 30 years rising by 0.2°C per decade. The frequency and intensity of extreme weather events, and the fires, floods and droughts that they can bring, have increased in the past 50 years, while the global average sea level has risen by between 16 and 21 cm since 1900, and at a rate of more than 3 mm per year over the past two decades. These changes have contributed to widespread impacts in many aspects of biodiversity, including species distribution, phenology, population dynamics, community structure and ecosystem function. According to observational evidence, the effects are accelerating in marine, terrestrial and freshwater ecosystems and are already impacting agriculture, aquaculture, fisheries and nature's contributions to people. The compounding effects of drivers such as climate change, land-/sea-use change, overexploitation of resources, pollution and invasive alien species are likely to exacerbate the negative impacts on nature, as seen in different ecosystems including coral reefs, the Arctic systems and savannas.

B3 Many types of pollution, as well as invasive alien species, are increasing, with negative impacts for nature. Although global trends are mixed, air, water and soil pollution have continued to increase in some areas. Marine plastic pollution in particular has increased tenfold since 1980, affecting at least 267 species, including 86 per cent of marine turtles, 44 per cent of seabirds and 43 per cent of marine mammals. This can affect humans through food chains. Greenhouse gas emissions, untreated urban and rural waste, pollutants from industrial, mining and agricultural activities, oil spills and toxic dumping have had strong negative effects on soil, freshwater and marine water quality and on the global atmosphere. Cumulative records of alien species have increased by 40 per cent since 1980, associated with increased trade and human population dynamics and trends. Nearly one fifth of the Earth's surface is at risk of plant and animal invasions, impacting native species, ecosystem functions and nature's contributions to people, as well as economies and human health. The rate of introduction of new invasive alien species seems higher than ever before and shows no signs of slowing.

B4 In the past 50 years, the human population has doubled, the global economy has grown nearly fourfold and global trade has grown tenfold, together driving up the demand for energy and materials. A variety of economic, political and social factors, including global trade and the spatial decoupling of production from consumption, have shifted the economic and environmental gains and losses of production and consumption, contributing to new economic opportunities, but also to impacts on nature and its contributions to people. Levels of consumption of material goods (food, feed, timber and fibre) vary greatly, and unequal access to material goods can be associated with inequity and may lead to social conflict. Economic exchange contributes to aggregate economic development, yet often is negotiated between actors and institutions of unequal power, which influences the distribution of benefits and long-term impacts. Countries at different levels of development have experienced different levels of deterioration of nature for any given gain in economic growth. Exclusion, scarcity and/or the unequal distribution of nature's contributions to people may fuel social instability and conflict in a complex interaction with other factors. Armed conflicts have an impact on ecosystems beyond their destabilizing effects on societies, and a range of indirect impacts, including the displacement of people and activities.

B5 Economic incentives have generally favoured expanding economic activity, and often environmental harm, over conservation or restoration. Incorporating the consideration of the multiple values of ecosystem functions and of nature's contributions to people into economic incentives has, in the economy, been shown to permit better ecological, economic and social outcomes. Local, national, regional and global governance initiatives have improved outcomes in this way by supporting policies, innovation and the elimination of environmentally harmful subsidies, introducing incentives in line with the value of nature's contribution to people, increasing sustainable land-/sea-use management and enforcing regulations, among other measures. Harmful economic incentives and policies associated with unsustainable practices in fisheries, aquaculture, agriculture (including fertilizer and pesticide use), livestock management, forestry, mining and energy (including fossil fuels and biofuels) are often associated with land-/sea-use change and overexploitation of natural resources, as well as inefficient production and waste management. Vested interests may oppose the removal of subsidies or the introduction of other policies. Yet policy reforms to deal with such causes of environmental harm offer the potential to both conserve nature and provide economic benefits, including when policies are based on more and better understanding of the multiple values of nature's contributions.

B6 Nature managed by indigenous peoples and local communities is under increasing pressure. Nature is generally declining less rapidly in indigenous peoples' land than in other lands, but is nevertheless declining, as is the knowledge of how to manage it. At least a quarter of the global land area is traditionally owned, managed[4], used or occupied by indigenous peoples. These areas include approximately 35 per cent of the area that is formally protected, and approximately 35 per cent of all remaining terrestrial areas with very low human intervention. In addition, a diverse array of local communities, including farmers, fishers, herders, hunters, ranchers and forest users, manage significant areas under various property and access regimes. Among the local indicators developed and used by indigenous peoples and local communities, 72 per cent show negative trends in nature that underpin local livelihoods and well-being. The areas managed (under various types of tenure and access regimes) by indigenous peoples and local communities are facing growing resource extraction, commodity production, mining and transport and energy infrastructure, with various consequences for local livelihoods and health. Some climate change mitigation programmes have had negative impacts on indigenous peoples and local communities. The negative impacts of all these pressures include continued loss of subsistence and traditional livelihoods resulting from ongoing deforestation, loss of wetlands, mining, the spread of unsustainable agriculture, forestry and fishing practices and impacts on health and well-being from pollution and water insecurity. These impacts also challenge traditional management, the transmission of indigenous and local knowledge, the potential for sharing of benefits arising from the use of, and the ability of indigenous peoples and local communities to conserve and sustainably manage, wild and domesticated biodiversity that are also relevant to broader society.

C. Goals for conserving and sustainably using nature and achieving sustainability cannot be met by current trajectories, and goals for 2030 and beyond may only be achieved through transformative changes[5] across economic, social, political and technological factors.

Past and ongoing rapid declines in biodiversity, ecosystem functions and many of nature's contributions to people mean that most international societal and environmental goals, such as those embodied in the Aichi Biodiversity Targets and the 2030 Agenda for Sustainable Development, will not be achieved based on current trajectories. These declines will also undermine other goals, such as those specified in the Paris Agreement adopted under the United Nations Framework Convention on Climate Change and the 2050 Vision for Biodiversity.

4. These data sources define land management here as the process of determining the use, development and care of land resources in a manner that fulfils material and non-material cultural needs, including livelihood activities such as hunting, fishing, gathering, resource harvesting, pastoralism and small-scale agriculture and horticulture.

5. A fundamental, system-wide reorganization across technological, economic and social factors, including paradigms, goals and values.

The negative trends in biodiversity and ecosystem functions are projected to continue or worsen in many future scenarios in response to indirect drivers such as rapid human population growth, unsustainable production and consumption and associated technological development. In contrast, scenarios and pathways that explore the effects of low-to-moderate population growth, and transformative changes in the production and consumption of energy, food, feed, fibre and water, sustainable use, equitable sharing of the benefits arising from use and nature-friendly climate adaptation and mitigation will better support the achievement of future societal and environmental objectives.

C1 **The implementation of policy responses and actions to conserve nature and manage it more sustainably has progressed, yielding positive outcomes relative to scenarios of no intervention, but progress is not sufficient to stem the direct and indirect drivers of nature deterioration. It is therefore likely that most of the Aichi Biodiversity Targets for 2020 will be missed.** Some of the Aichi Biodiversity Targets will be partially achieved, for example those related to policy responses, such as the spatial extent of terrestrial and marine protected areas, the identification and prioritization of invasive alien species, national biodiversity strategies and action plans, and the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity. However, while protected areas now cover 15 per cent of terrestrial and freshwater environments and 7 per cent of the marine realm, they only partly cover important sites for biodiversity and are not yet fully ecologically representative and effectively or equitably managed. There has been significant growth in official development assistance in support of the Convention on Biological Diversity and in funding provided by the Global Environment Facility, with biodiversity aid flows reaching $8.7 billion annually. However, current resource mobilization from all sources is not sufficient to achieve the Aichi Biodiversity Targets. In addition, only one in five of the strategic objective and goals across six global agreements[6] relating to nature and the protection of the global environment are demonstrably on track to be met. For nearly one third of the goals of these conventions, there has been little or no progress towards them or, instead, movement away from them.

C2 **Nature is essential for achieving the Sustainable Development Goals. However, taking into consideration that the Sustainable Development Goals are integrated, indivisible, and nationally implemented, current negative trends in biodiversity and ecosystems will undermine progress towards 80 per cent (35 out of 44) of the assessed targets of Goals related to poverty, hunger, health, water, cities, climate, oceans and land (Sustainable Development Goals 1, 2, 3, 6, 11, 13, 14, and 15).** Important positive synergies between nature and the Goals related to education, gender equality, reducing inequalities and promoting peace and justice (Sustainable Development Goals 4, 5, 10 and 16) were found. Land or resource tenure insecurity, as well as declines in nature, have greater impacts on women and girls, who are most often negatively impacted. However, the current focus and wording of the targets of these Goals obscures or omits their relationship to nature, thereby preventing their assessment here. There is a critical need for future policy targets, indicators and datasets to more explicitly account for aspects of nature and their relevance to human well-being in order to more effectively track the consequences of trends in nature on the Sustainable Development Goals. Some pathways chosen to achieve the Goals related to energy, economic growth, industry and infrastructure, and sustainable consumption and production (Sustainable Development Goals 7, 8, 9 and 12), as well as the targets related to poverty, food security and cities (Sustainable Development Goals 1, 2 and 11), could have substantial positive or negative impacts on nature and therefore on the achievement of the other Sustainable Development Goals.

C3 **Areas of the world projected to experience significant negative effects from global changes in climate, biodiversity, ecosystem functions and nature's contributions to people are also home to large concentrations of indigenous peoples and many of the world's poorest communities.** Because of their strong dependency on nature and its contributions for subsistence, livelihoods and health, those communities will be disproportionately hard-hit by those negative changes. Those negative effects also influence the ability of indigenous peoples and local communities to manage and conserve wild and domesticated biodiversity and nature's contributions to people. Indigenous peoples and local communities have been proactively confronting such challenges in partnership with each other and with an array of other stakeholders, through co-management systems

6. Convention on the Conservation of Migratory Species of Wild Animals, Convention on International Trade in Endangered Species of Wild Fauna and Flora, Convention concerning the Protection of the World Cultural and Natural Heritage, International Plant Protection Convention, United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa, and Convention on Wetlands of International Importance especially as Waterfowl Habitat.

and local and regional monitoring networks and by revitalizing and adapting local management systems. Regional and global scenarios lack an explicit consideration of the views, perspectives and rights of indigenous peoples and local communities, their knowledge and understanding of large regions and ecosystems, and their desired future development pathways.

C4 **Except in scenarios that include transformative change, negative trends in nature, in ecosystem functions and in many of nature's contributions to people are projected to continue to 2050 and beyond, due to the projected impacts of increasing land-/and sea-use change, exploitation of organisms and climate change.** Negative impacts arising from pollution and invasive alien species will likely exacerbate these trends. There are large regional differences in the projected patterns of future biodiversity and ecosystem functions and in the losses and changes in nature's contributions to people. These differences arise from the direct and indirect drivers of change, which are projected to impact regions in different ways. While regions worldwide face further declines in biodiversity in future projections, tropical regions face particular combined risks of declines due to the interactions between climate change, land-use change and fisheries exploitation. Marine and terrestrial biodiversity in boreal, subpolar and polar regions is projected to decline mostly because of warming, sea ice retreat and enhanced ocean acidification. The magnitude of the impacts and the differences between regions are much greater in scenarios with rapid increases in consumption or human population than in scenarios based on sustainability. Acting immediately and simultaneously on the multiple indirect and direct drivers has the potential to slow, halt and even reverse some aspects of biodiversity and ecosystem loss.

C5 **Climate change is projected to become increasingly important as a direct driver of changes in nature and its contributions to people in the next decades. Scenarios show that meeting the Sustainable Development Goals and the 2050 Vision for Biodiversity depends on taking into account climate change impacts in the definition of future goals and objectives.** The future impacts of climate change are projected to become more pronounced in the next decades, with variable relative effects depending on scenario and geographic region. Scenarios project mostly adverse climate change effects on biodiversity and ecosystem functioning, which worsen, in some cases exponentially, with incremental global warming. Even for global warming of 1.5°C to 2°C, the majority of terrestrial species ranges are projected to shrink dramatically. Changes in ranges can adversely affect the capacity of terrestrial protected areas to conserve species, greatly increase local species turnover and substantially increase the risk of global extinctions. For example, a synthesis of many studies estimates that the fraction of species at risk of climate-related extinction is 5 per cent at 2°C warming and rises to 16 per cent at 4.3°C warming. Coral reefs are particularly vulnerable to climate change and are projected to decline to 10 to 30 per cent of former cover at 1.5°C warming and to less than 1 per cent of former cover at 2°C warming. Therefore, scenarios show that limiting global warming to well below 2°C plays a critical role in reducing adverse impacts on nature and its contributions to people.

D. Nature can be conserved, restored and used sustainably while other global societal goals are simultaneously met through urgent and concerted efforts fostering transformative change.

Societal goals, including those related to food, water, energy, health and the achievement of human well-being for all, mitigating and adapting to climate change and conserving and sustainably using nature, can be achieved in sustainable pathways through the rapid and improved deployment of existing policy instruments and new initiatives that more effectively enlist individual and collective action for transformative change. Since current structures often inhibit sustainable development and actually represent the indirect drivers of biodiversity loss, such fundamental, structural change is called for. By its very nature, transformative change can expect opposition from those with interests vested in the status quo, but such opposition can be overcome for the broader public good. If obstacles are overcome, a commitment to mutually supportive international goals and targets, supporting actions by indigenous peoples and local communities at the local level, new frameworks for private sector investment and innovation, inclusive and adaptive governance approaches and arrangements, multi-sectoral planning, and strategic policy mixes can help to transform the public and private sectors to achieve sustainability at the local, national and global levels.

D1 **The global environment can be safeguarded through enhanced international cooperation and linked, locally relevant measures. The review and renewal of internationally agreed environment-related goals and targets, based on the best available scientific knowledge and the widespread adoption and funding of action on conservation, ecological restoration and sustainable use by all actors, including individuals, are key to this safeguarding.** Such widespread adoption implies advancing and aligning local, national and international sustainability efforts and mainstreaming biodiversity and sustainability across all extractive and productive sectors, including mining, fisheries, forestry and agriculture, so that together, individual and collective actions result in a reversal of the deterioration of ecosystem services at the global level. Yet these bold changes to the direct drivers of the deterioration of nature cannot be achieved without transformative change that simultaneously addresses the indirect drivers.

D2 **Five main interventions ("levers") can generate transformative change by tackling the underlying indirect drivers of the deterioration of nature: (1) incentives and capacity-building; (2) cross-sectoral cooperation; (3) pre-emptive action; (4) decision-making in the context of resilience and uncertainty; and (5) environmental law and implementation.** Using these levers will involve the following: (1) developing incentives and widespread capacity for environmental responsibility and eliminating perverse incentives; (2) reforming sectoral and segmented decision-making to promote integration across sectors and jurisdictions; (3) taking pre-emptive and precautionary actions in regulatory and management institutions and businesses to avoid, mitigate and remedy the deterioration of nature, and monitoring their outcomes; (4) managing for resilient social and ecological systems in the face of uncertainty and complexity, to deliver decisions that are robust in a wide range of scenarios; and (5) strengthening environmental laws and policies and their implementation, and the rule of law more generally. All five levers may require new resources, particularly in low-capacity contexts, such as in many developing countries.

D3 **Transformations towards sustainability are more likely when efforts are directed at the following key leverage points, where efforts yield exceptionally large effects (Figure SPM.9): (1) visions of a good life; (2) total consumption and waste; (3) values and action; (4) inequalities; (5) justice and inclusion in conservation; (6) externalities and telecouplings; (7) technology, innovation and investment; and (8) education and knowledge generation and sharing.** Specifically, the following changes are mutually reinforcing: (1) enabling visions of a good quality of life that do not entail ever-increasing material consumption; (2) lowering total consumption and waste, including by addressing both population growth and per capita consumption differently in different contexts; (3) unleashing existing, widely-held values of responsibility to effect new social norms for sustainability, especially by extending notions of responsibility to include the impacts associated with consumption; (4) addressing inequalities, especially regarding income and gender, which undermine the capacity for sustainability; (5) ensuring inclusive decision-making and the fair and equitable sharing of benefits arising from the use of and adherence to human rights in conservation decisions; (6) accounting for nature deterioration from local economic activities and socioeconomic and environmental interactions over distances (telecouplings), including, for example, international trade; (7) ensuring environmentally friendly technological and social innovation, taking into account potential rebound effects and investment regimes; and (8) promoting education, knowledge generation and the maintenance of different knowledge systems, including in the sciences and indigenous and local knowledge, regarding nature, conservation and its sustainable use.

D4 **The character and trajectories of transformation will vary across contexts, with challenges and needs differing, among others, in developing and developed countries. Risks related to the inevitable uncertainties and complexities in transformations towards sustainability can be reduced through governance approaches that are integrative, inclusive, informed and adaptive.** Such approaches typically take into account the synergies and trade-offs between societal goals and alternative pathways and recognize a plurality of values, diverse economic conditions, inequity, power imbalances and vested interests in society. Risk-reducing strategies typically include learning from experience that is based on a combination of precautionary measures and existing and emerging knowledge. These approaches involve stakeholders in the coordination of policies across sectors and in the creation of strategic, locally relevant mixes of successful policy instruments. The private sector can play a role in partnership with other actors, including national and subnational governments and civil society; for example, public-private partnerships in the water sector have been an important vehicle for financing investments to meet the Sustainable Development Goals. Some effective policy measures include the expansion and strengthening of ecologically representative, well-connected protected-area networks and of other effective area-based conservation measures; the protection of watersheds; and incentives and sanctions to reduce pollution **(Table SPM.1)**.

D5 Recognizing the knowledge, innovations, practices, institutions and values of indigenous peoples and local communities, and ensuring their inclusion and participation in environmental governance, often enhances their quality of life and the conservation, restoration and sustainable use of nature, which is relevant to broader society. Governance, including customary institutions and management systems and co-management regimes that involve indigenous peoples and local communities, can be an effective way to safeguard nature and its contributions to people by incorporating locally attuned management systems and indigenous and local knowledge. The positive contributions of indigenous peoples and local communities to sustainability can be facilitated through national recognition of land tenure, access and resource rights in accordance with national legislation, the application of free, prior and informed consent, and improved collaboration, fair and equitable sharing of benefits arising from the use, and co-management arrangements with local communities.

D6 Feeding humanity and enhancing the conservation and sustainable use of nature are complementary and closely interdependent goals that can be advanced through sustainable agriculture, aquaculture and livestock systems, the safeguarding of native species, varieties, breeds and habitats, and ecological restoration. Specific actions include promoting sustainable agricultural and agroecological practices, such as multifunctional landscape planning and cross-sectoral integrated management, that support the conservation of genetic diversity and the associated agricultural biodiversity. Further actions to simultaneously achieve food security, biodiversity protection and sustainable use are context appropriate climate change mitigation and adaptation; incorporating knowledge from various systems, including the sciences and sustainable indigenous and local practices; avoiding food waste; empowering producers and consumers to transform supply chains; and facilitating sustainable and healthy dietary choices. As part of integrated landscape planning and management, prompt ecological restoration, emphasizing the use of native species, can offset the current degradation and save many endangered species, but is less effective if delayed.

D7 Sustaining and conserving fisheries and marine species and ecosystems can be achieved through a coordinated mix of interventions on land, in freshwater and in the oceans, including multilevel coordination across stakeholders on the use of open oceans. Specific actions could include, for example, ecosystem-based approaches to fisheries management, spatial planning, effective quotas, marine protected areas, protecting and managing key marine biodiversity areas, reducing run-off pollution into oceans and working closely with producers and consumers **(Table SPM.1)**. It is important to enhance capacity-building for the adoption of best fisheries management practices; adopt measures to promote conservation financing and corporate social responsibility; develop new legal and binding instruments; implement and enforce global agreements for responsible fisheries; and urgently take all steps necessary to prevent, deter and eliminate illegal, unreported and unregulated fishing.

D8 Land-based climate change mitigation activities can be effective and support conservation goals (Table SPM.1). However, the large-scale deployment of bioenergy plantations and afforestation of non-forest ecosystems can come with negative side effects for biodiversity and ecosystem functions. Nature-based solutions with safeguards are estimated to provide 37 per cent of climate change mitigation until 2030 needed to meet the goal of keeping climate warming below 2°C, with likely co-benefits for biodiversity. Therefore, land-use actions are indispensable, in addition to strong actions to reduce greenhouse gas emissions from fossil fuel use and other industrial and agricultural activities. However, the large-scale deployment of intensive bioenergy plantations, including monocultures, replacing natural forests and subsistence farmlands, will likely have negative impacts on biodiversity and can threaten food and water security as well as local livelihoods, including by intensifying social conflict.

D9 Nature-based solutions can be cost-effective for meeting the Sustainable Development Goals in cities, which are crucial for global sustainability. Increased use of green infrastructure and other ecosystem-based approaches can help to advance sustainable urban development while reinforcing climate mitigation and adaptation. Urban key biodiversity areas should be safeguarded. Solutions can include retrofitting green and blue infrastructure, such as creating and maintaining green spaces and biodiversity-friendly water bodies, urban agriculture, rooftop gardens and expanded and accessible vegetation cover in existing urban and peri-urban areas and new developments. Green infrastructure in urban and surrounding rural areas can complement large-scale "grey infrastructure" in areas such as flood protection, temperature regulation, cleaning of air and water, treating wastewater and the provision of energy, locally sourced food and the health benefits of interaction with nature.

D10 A key component of sustainable pathways is the evolution of global financial and economic

systems to build a global sustainable economy, steering away from the current, limited paradigm of economic growth. That implies incorporating the reduction of inequalities into development pathways, reducing overconsumption and waste and addressing environmental impacts, such as externalities of economic activities, from the local to the global scales. Such an evolution could be enabled through a mix of policies and tools (such as incentive programmes, certification and performance standards) and through more internationally consistent taxation, supported by multilateral agreements and enhanced environmental monitoring and evaluation. It would also entail a shift beyond standard economic indicators such as gross domestic product to include those able to capture more holistic, long-term views of economics and quality of life.

BACK-GROUND

BACKGROUND

A. Nature and its vital contributions to people, which together embody biodiversity and ecosystem functions and services, are deteriorating worldwide.

1 **Nature underpins quality of life by providing basic life support for humanity (regulating), as well as material goods (material) and spiritual inspiration (non-material) *(well established)* {2.3.1, 2.3.2}. Most of nature's contributions to people (NCP) are co-produced by biophysical processes and ecological interactions with anthropogenic assets such as knowledge, infrastructure, financial capital, technology and the institutions that mediate them *(well established)* {2.3.2} (Appendix I)**. For example, marine and freshwater-based food is co-produced by the combination of fish populations, fishing gear, and access to fishing grounds {2.3.3} There is unequal access to nature's contributions and unequal impact of nature's contributions on different social groups *(established but incomplete)* {2.3.5}. Furthermore, increases in the production of some of nature's contributions cause declines in others **(Figure SPM.1)** {2.3.2, 2.3.5}, which also affects people differently *(well established)*. For example, clearing of forest for agriculture has increased the supply of food, feed, (NCP 12) and other materials important for people (such as natural fibres and ornamental flowers: NCP 13), but has reduced contributions as diverse as pollination (NCP 2), climate regulation (NCP 4), water quality regulation (NCP 7), opportunities for learning and inspiration (NCP 15) and the maintenance of options for the future (NCP 18). However, very few large-scale systematic studies exist on those relationships {2.3.2}. Land degradation has reduced productivity in 23 per cent of the global terrestrial area, and between $235 billion and $577 billion in annual global crop output is at risk as a result of pollinator loss {2.3.5.3} *(established but incomplete).*

2 **Many of nature's contributions to people are essential for human health (*well established*) and their decline thus threatens a good quality of life (*established but incomplete*) {2.3.4}.** Nature provides a broad diversity of nutritious foods, medicines and clean water *(well established)* {2.3.5.2, 3.3.2.1, 3.3.2.2 (Sustainable Development Goal 3)}; can help to regulate disease and the immune system {2.3.4.2}; can reduce levels of certain air pollutants *(established but incomplete)* {2.3.4.2, 3.3.2.2}; and can improve mental and physical health through exposure to natural areas *(inconclusive)*, among other contributions {2.3.2.2, 2.3.4.2, 3.3.2.2 (Sustainable Development Goal 3)}. Nature is the origin of most infectious diseases (negative impact), but also the source of medicines and antibiotics for treatment (positive contribution) *(well established)*. Zoonotic diseases are significant threats to human health, with vector-borne diseases accounting for approximately 17 per cent of all infectious diseases and causing an estimated 700,000 deaths globally per annum *(established but incomplete)* {3.3.2.2}. Emerging infectious diseases in wildlife, domestic animals, plants or people can be exacerbated by human activities such as land clearing and habitat fragmentation *(established but incomplete)* or the overuse of antibiotics driving rapid evolution of antibiotic resistance in many bacterial pathogens *(well established)* {3.3.2.2}. The deterioration of nature and consequent disruption of benefits to people has both direct and indirect implications for public health *(well established)* {2.3.5.2} and can exacerbate existing inequalities in access to health care or healthy diets *(established but incomplete)* {2.3.4.2}. Shifting diets towards a diversity of foods, including fish, fruit, nuts and vegetables, significantly reduces the risk of certain preventable non-communicable diseases, which are currently responsible for 20 per cent of premature mortality globally *(well established)* {2.3.4.2, 2.3.5.2 (NCP 2 and 12)}.

3 **Most of nature's contributions are not fully replaceable, yet some contributions of nature are irreplaceable (*well established*).** Loss of diversity, such as phylogenetic and functional diversity, can permanently reduce future options, such as wild species that might be domesticated as new crops and be used for genetic improvement {2.3.5.3}. People have created substitutes for some other contributions of nature, but many of them are imperfect or financially prohibitive {2.3.2.2}. For example, high-quality drinking water can be realized either through ecosystems that filter pollutants or through human-engineered water treatment facilities {2.3.5.3}. Similarly, coastal flooding from storm surges can be reduced either by coastal mangroves or by dikes and sea walls {2.3.5.3}. In both cases, however, built infrastructure can be extremely expensive, incur high future costs and fail to provide synergistic benefits such as nursery habitats for edible fish or recreational opportunities {2.3.5.2}. More generally, human-made replacements often do not provide the full range of benefits provided by nature {2.3.2.2} **(Figure SPM.1)**.

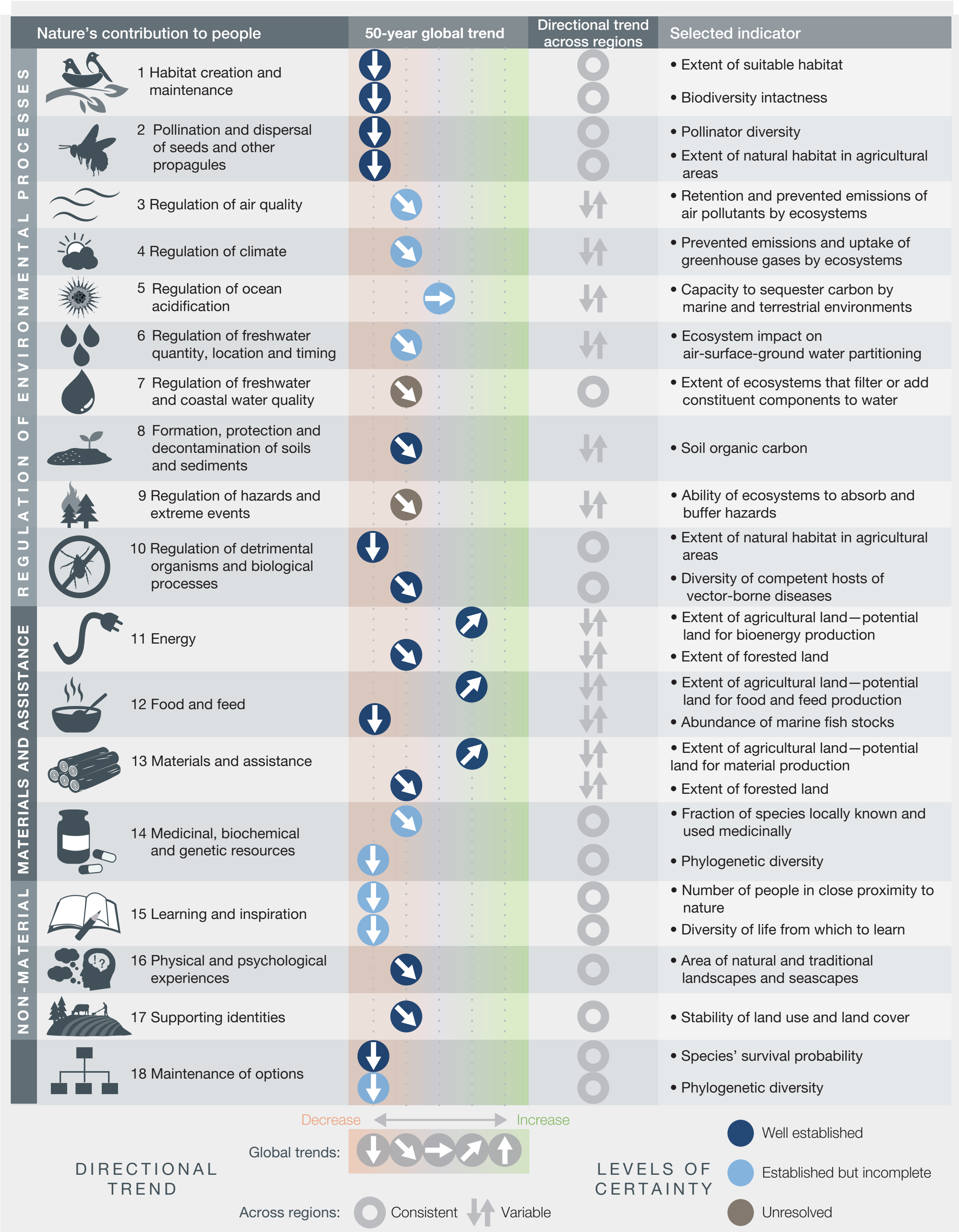

Figure SPM 1 **Global trends in the capacity of nature to sustain contributions to good quality of life from 1970 to the present, which show a decline for 14 of the 18 categories of nature's contributions to people analysed.**

Data supporting global trends and regional variations come from a systematic review of over 2,000 studies {2.3.5.1}. Indicators were selected on the basis of availability of global data, prior use in assessments and alignment with 18 categories. For many categories of nature's contributions, two indicators are included that show different aspects of nature's capacity to contribute to human well-being within that category. Indicators are defined so that an increase in the indicator is associated with an improvement in nature's contributions.

4 Humanity is a dominant global influence on life on earth, and has caused natural terrestrial, freshwater and marine ecosystems to decline (*well established*) {2.2.5.2} (Figure SPM.2). Global indicators of ecosystem extent and condition have shown a decrease by an average of 47 per cent of their estimated natural baselines, with many continuing to decline by at least 4 per cent per decade *(established but incomplete)* {2.2.5.2.1}. On land, particularly sensitive ecosystems include old-growth forests, insular ecosystems, and wetlands; and only around 25 per cent of land is sufficiently unimpacted that ecological and evolutionary processes still operate with minimal human intervention *(established but incomplete)* {2.2.3.4.1, 2.2.5.2.1}. In terrestrial "hotspots" of endemic species, natural habitats have generally undergone greater reductions to date in extent and condition, and tend to be experiencing more rapid ongoing decline, on average than other terrestrial regions {2.2.5.2.1}. Globally, the net rate of forest loss has halved since the 1990s, largely because of net increases in temperate and high latitude forests; high-biodiversity tropical forests continue to dwindle, and global forest area is now approximately 68 per cent of the estimated pre-industrial level *(established but incomplete)* {2.2.5.2.1}. Forests and natural mosaics sufficiently undamaged to be classed as "intact" (defined as being larger than 500 km^2 where satellites can detect no human pressure) were reduced by 7 per cent (919, 000 km^2) between 2000 and 2013, shrinking in both developed and developing countries {2.2.5.2.1}. Inland waters and freshwater ecosystems show among the highest rates of decline. Only 13 per cent of the wetland present in 1700 remained by 2000; recent losses have been even more rapid (0.8 per cent per year from 1970 to 2008) *(established but incomplete)* {2.2.7.9}.

5 Marine ecosystems, from coastal to deep sea, now show the influence of human actions, with coastal marine ecosystems showing both large historical losses of extent and condition as well as rapid ongoing declines (*established but incomplete*) {2.2.5.2.1, 2.2.7.15} (Figure SPM.2). Over 40 per cent of ocean area was strongly affected by multiple drivers in 2008, and 66 per cent was experiencing increasing cumulative impacts in 2014. Only 3 per cent of the ocean was described as free from human pressure in 2014 *(established but incomplete)* {2.2.5.2.1, 3.2.1}. Seagrass meadows decreased in extent by over 10 per cent per decade from 1970 to 2000 *(established but incomplete)* {2.2.5.2.1}. Live coral cover on reefs has nearly halved in the past 150 years, the decline dramatically accelerating over the past two or three decades due to increased water temperature and ocean acidification interacting with and further exacerbating other drivers of loss *(well established)* {2.2.5.2.1}. These coastal marine ecosystems are among the most productive systems globally, and their loss and deterioration reduce their ability to protect shorelines, and the people and species that live there, from storms, as well as their ability to provide sustainable livelihoods *(well established)* {2.2.5.2.1, 2.3.5.2}. Severe impacts to ocean ecosystems are illustrated by 33 per cent of fish stocks being classified as overexploited and greater than 55 per cent of ocean area being subject to industrial fishing *(established but incomplete)* {2.1.11.1, 2.2.5.2.4, 2.2.7.16}.

6 The global rate of species extinction is already at least tens to hundreds of times higher than the average rate over the past 10 million years and is accelerating (*established but incomplete*) {2.2.5.2.4} (Figure SPM.3). Human actions have already driven at least 680 vertebrate species to extinction since 1500, including the Pinta Giant Tortoise in the Galapagos in 2012, even though successful conservation efforts have saved from extinction at least 26 bird species and 6 ungulate species, including the Arabian Oryx and Przewalski's Horse {3.2.1}. The threat of extinction is also accelerating: in the best-studied taxonomic groups, most of the total extinction risk to species is estimated to have arisen in the past 40 years *(established but incomplete)* {2.2.5.2.4}. The proportion of species currently threatened with extinction according to the International Union for the Conservation of Nature's Red List criteria averages around 25 per cent across the many terrestrial, freshwater and marine vertebrate, invertebrate and plant groups that have been studied in sufficient detail to support a robust overall estimate *(established but incomplete)* {2.2.5.2.4, 3.2}. More than 40 per cent of amphibian species, almost a third of reef-forming corals, sharks and shark relatives and over a third of marine mammals are currently threatened {2.2.5.2.4, 3}. The proportion of insect species threatened with extinction is a key uncertainty, but available evidence supports a tentative estimate of 10 per cent *(established but incomplete)* {2.2.5.2.4}. Those proportions suggest that, of an estimated 8 million animal and plant species (75 per cent of which are insects), around 1 million are threatened with extinction *(established but incomplete)* {2.2.5.2.4}. A similar picture also emerges from an entirely separate line of evidence. Habitat loss and deterioration, largely caused by human actions, have reduced global terrestrial habitat integrity by 30 per cent relative to an unimpacted baseline; combining that with the longstanding relationship between habitat area and species numbers suggests that around 9 per cent of the world's estimated 5.9 million terrestrial species – more than 500,000 species – have insufficient habitat for long-term survival, and are committed to extinction, many within decades, unless their habitats are restored *(established but incomplete)* {2.2.5.2.4}. Population declines often give warning that a species' risk of extinction is increasing. The Living Planet Index, which synthesises trends in vertebrate populations, shows that species have declined rapidly since 1970, with reductions of 40 per cent for terrestrial species, 84 per cent for freshwater species and 35 per cent for marine species *(established but*

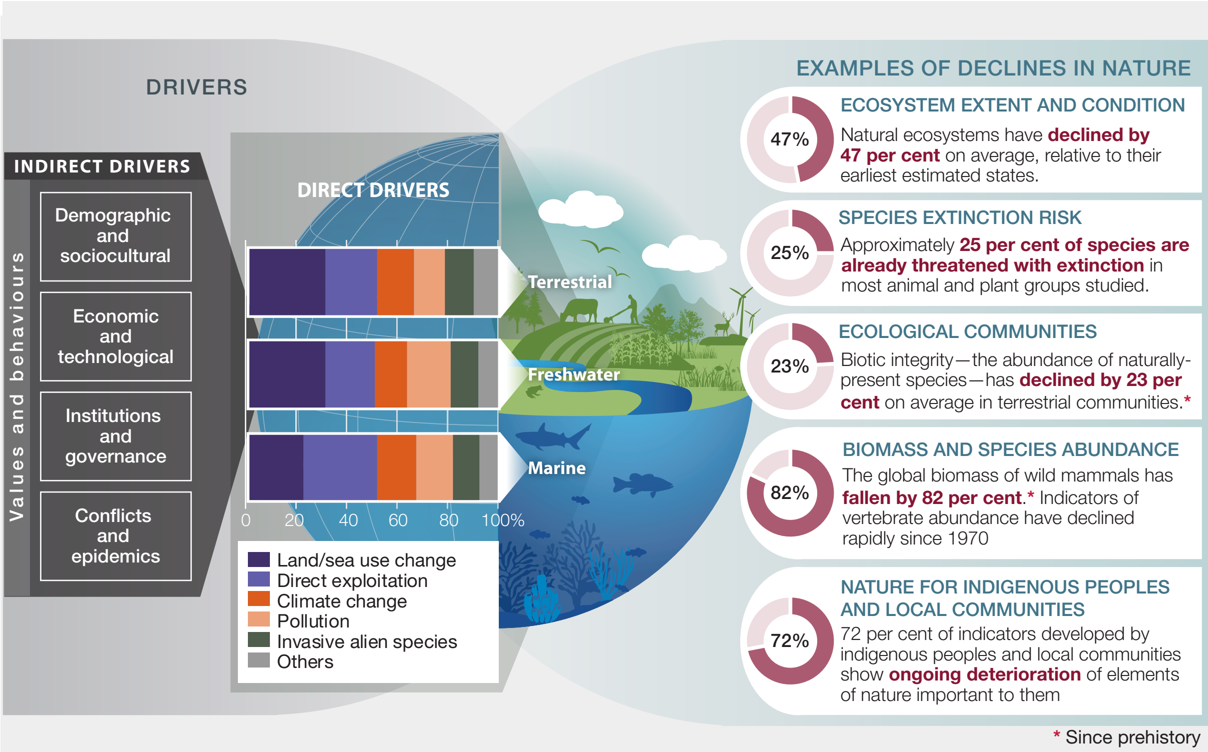

Figure SPM 2 **Examples of global declines in nature, emphasizing declines in biodiversity, that have been and are being caused by direct and indirect drivers of change.**

The direct drivers (land-/sea-use change; direct exploitation of organisms; climate change; pollution; and invasive alien species)[7] result from an array of underlying societal causes[8]. These causes can be demographic (e.g., human population dynamics), sociocultural (e.g., consumption patterns), economic (e.g., trade), technological, or relating to institutions, governance, conflicts and epidemics. They are called indirect drivers[9] and are underpinned by societal values and behaviours. The colour bands represent the relative global impact of direct drivers, from top to bottom, on terrestrial, freshwater and marine nature, as estimated from a global systematic review of studies published since 2005. Land- and sea-use change and direct exploitation account for more than 50 per cent of the global impact on land, in fresh water and in the sea, but each driver is dominant in certain contexts {2.2.6}. The circles illustrate the magnitude of the negative human impacts on a diverse selection of aspects of nature over a range of different time scales based on a global synthesis of indicators {2.2.5, 2.2.7}.

incomplete) {2.2.5.2.4}. Local declines of insect populations such as wild bees and butterflies have often been reported, and insect abundance has declined very rapidly in some places even without large-scale land-use change, but the global extent of such declines is not known *(established but incomplete)* {2.2.5.2.4}. On land, wild species that are endemic (narrowly distributed) have typically seen larger-than-average changes to their habitats and shown faster-than-average declines *(established but incomplete)* {2.2.5.2.3, 2.2.5.2.4}.

7 The number of local varieties and breeds of domesticated plants and animals and their wild relatives has been reduced sharply as a result of land use change, knowledge loss, market preferences and large-scale trade (*well established*) {2.2.5.2.6, 2.2.5.3.1}. Domestic varieties of plants and animals are the result of natural and human-managed selection, sometimes over centuries or millennia, and tend to show a high degree of adaptation (genotypic and phenotypic) to local conditions *(well established)* {2.2.4.4}. As a result, the pool of genetic variation which underpins food security has declined *(well established)* {2.2.5.2.6}. Ten per cent of domesticated breeds of mammals were recorded as extinct, as well as some 3.5 per cent of domesticated breeds of birds *(well established)* {2.2.5.2.6}. Many hotspots of agrobiodiversity and crop wild relatives are also under threat or not formally protected. The conservation status of wild relatives of domesticated livestock has also deteriorated. These wild relatives represent critical reservoirs of genes and traits that may provide resilience against future climate change, pests and pathogens and may improve current heavily depleted gene pools of many crops and domestic animals {2.2.3.4.3}. The lands of

7. The classification of direct drivers used throughout this assessment is in {2.1.12 - 2.1.17}.
8. The interactions among indirect and direct drivers are addressed in {2.1.11, 2.1.18}.
9. The classification of indirect drivers used throughout this assessment is in {2.1.3 - 2.1.10}.

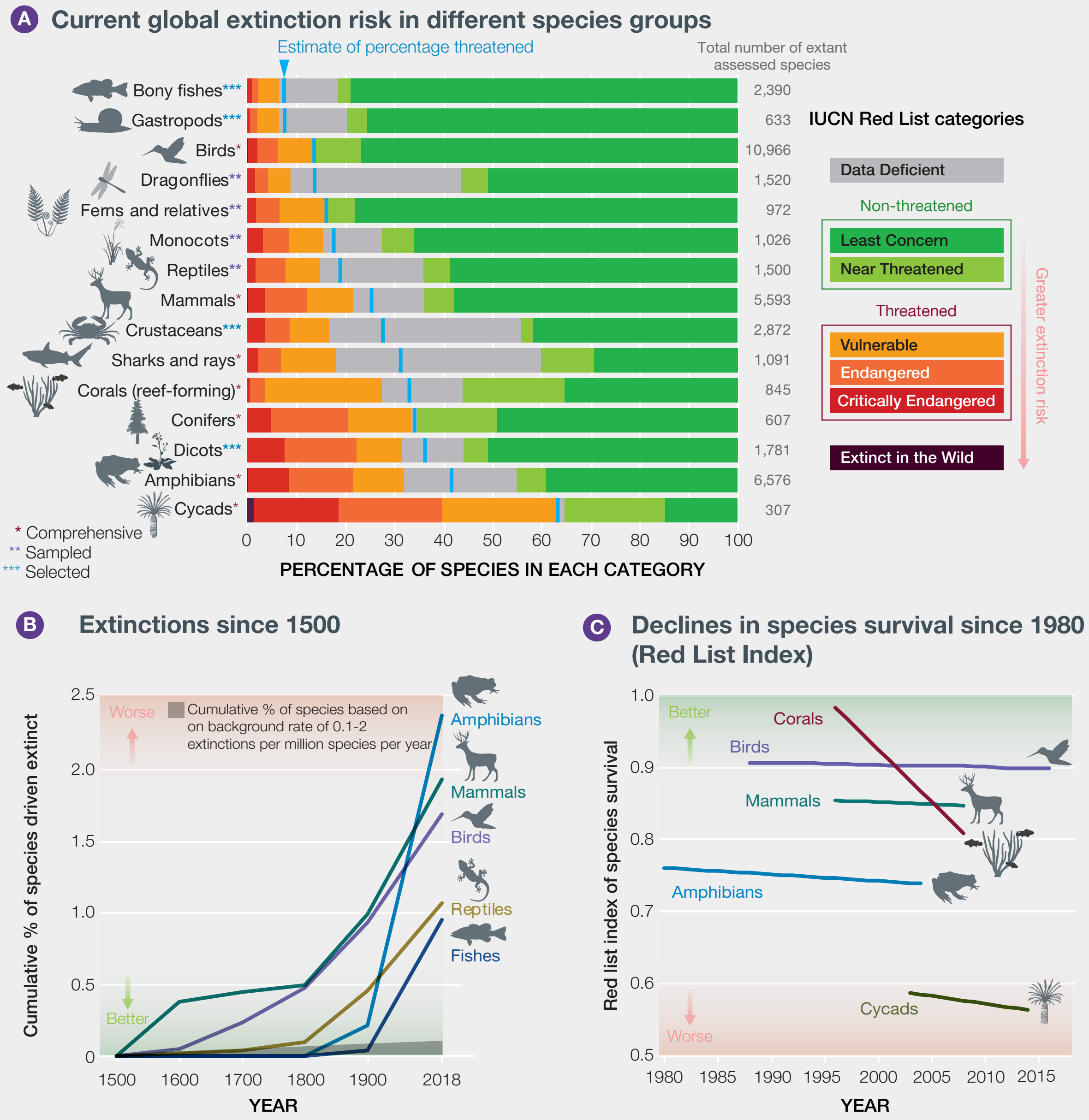

Figure SPM 3 **A substantial proportion of assessed species are threatened with extinction and overall trends are deteriorating, with extinction rates increasing sharply in the past century.**

A Percentage of species threatened with extinction in taxonomic groups that have been assessed comprehensively, or through a 'sampled' approach, or for which selected subsets have been assessed, by the International Union for Conservation of Nature (IUCN) Red List of Threatened Species. Groups are ordered according to the best estimate for the percentage of extant species considered threatened (shown by the vertical blue lines), assuming that data deficient species are as threatened as non-data deficient species. B Extinctions since 1500 for vertebrate groups. Rates for reptiles and fishes have not been assessed for all species. C Red List Index of species survival for taxonomic groups that have been assessed for the IUCN Red List at least twice. A value of 1 is equivalent to all species being categorized as Least Concern; a value of zero is equivalent to all species being classified as Extinct. Data for all panels derive from www.iucnredlist.org (see Chapter 3 Figure 3.4 and Chapter 2 Figure 2.7).

indigenous peoples and local communities, including farmers, pastoralists and herders, are often important areas for *in situ* conservation of the remaining varieties and breeds *(well established)* {2.2.5.3.1}. Available data suggest that genetic diversity within wild species globally has been declining by about 1 per cent per decade since the mid-19th century; and genetic diversity within wild mammals and amphibians tends to be lower in areas where human influence is greater *(established but incomplete)* {2.2.5.2.6}.

8 **Human-driven changes in species diversity within local ecological communities vary widely, depending on the net balance between species loss and the influx of alien species, disturbance-tolerant species, other human-adapted species or climate migrant species (*well established*) {2.2.5.2.3}.** Even though human-dominated landscapes are sometimes species-rich, their species composition is markedly altered from that in natural landscapes *(well established)* {2.2.5.2.3, 2.2.7.10, 2.2.7.11}. As a result of human-caused changes in community composition, naturally occurring species in local terrestrial ecosystems worldwide are estimated to have lost at least 20 per cent of their original abundance on average, with hotspots of endemic species tending to have lost even more *(established but incomplete)* {2.2.5.2.3}. The traits of species influence whether they persist or even thrive in human-modified ecosystems *(well established)* {2.2.3.6, 2.2.5.2.5}. For example, species that are large, grow slowly, are habitat specialists or are carnivores – such as great apes, tropical hardwood trees, sharks and big cats – are disappearing from many areas. Many other species, including those with opposite characteristics, are becoming more abundant locally and are spreading quickly around the world; across a set of 21 countries with detailed records, the numbers of invasive alien species per country have risen by some 70 per cent since 1970 {2.2.5.2.3}. The effects of invasive alien species are often particularly severe for the native species and assemblages on islands and in other settings with high proportions of endemic species *(well established)* {2.2.3.4.1, 2.2.5.2.3}. Invasive alien species can have devastating effects on mainland assemblages as well: for example, a single invasive pathogen species, *Batrachochytrium dendrobatidis*, is a threat to nearly 400 amphibian species worldwide and has already caused a number of extinctions *(well established)* {2.2.5.2.3}. Many drivers add already widespread species to ecological communities in many places; and many drivers cause endemic species to decline in many places. These two processes have contributed to the widespread erosion of differences between ecological communities in different places, a phenomenon known as biotic homogenization or the "anthropogenic blender" *(well established)* {2.2.5.2.3}. The consequences of all these changes for ecosystem processes and hence nature's contributions to people can be very significant. For example, the decline and disappearance of large herbivores and predators has dramatically affected the structure, fire regimes, seed dispersal, land surface albedo and nutrient availability within many ecosystems *(well established)* {2.2.5.2.1}. However, the consequences of changes often depend on details of the ecosystem, remain hard to predict and are still understudied *(established but incomplete)* {2.2.5.2.3}.

9 **Many organisms show ongoing biological evolution so rapid that it is detectable within only a few years or even more quickly – in response to anthropogenic drivers *(well established)* {2.2.5.2.5, 2.2.5.2.6}. Management decisions that take those evolutionary changes into account will be noticeably more effective (*established but incomplete*) {Box 2.5}.** This human-driven contemporary evolution, which has long been recognized in microbes, viruses, agricultural insect pests and weeds *(well established)*, is now being observed in some species within all major taxonomic groups (animals, plants, fungi and microorganisms). Such changes are known to occur in response to human activities or drivers, such as hunting, fishing, harvesting, climate change, ocean acidification, soil and water pollution, invasive species, pathogens, pesticides and urbanization *(established but incomplete)* {2.2.5.2.5}. However, management strategies typically assume that evolutionary changes occur only over much longer time periods and thus ignore rapid evolution. These policy considerations span many spheres in which management actions designed to slow or speed evolution can dramatically change outcomes, as the following examples indicate. Insects, weeds and pathogens evolve resistance to insecticides, herbicides and other control agents, yet management strategies such as refuges, crop rotation, and crop diversity can dramatically slow that undesirable evolution *(well established)* {Box 2.5}. Commercial fish populations have evolved to mature earlier under intensive harvesting, which sometimes can be minimized by mandating changes in fishing gear or fish size limits *(established but incomplete)* {2.2.5.2.5}. Climate change favours the evolution of seasonally earlier reproduction in many organisms, which can in principle be facilitated through the introduction of individuals from populations already adapted to such conditions *(established but incomplete)* {2.2.5.2.5}. Mosquitoes rapidly evolve resistance to efforts to control them, but evolutionarily informed management actions can dramatically slow that undesirable evolution *(established but incomplete)* {2.2.5.2.5}. Contemporary evolution is thus relevant to many policy concerns. Understanding and working with contemporary evolution can address important concerns surrounding pollination and dispersal, coral persistence in the face of ocean acidification, water quality, pest regulation, food production and options for the future *(established but incomplete).* The specific actions taken will typically be case-specific and therefore will require careful assessment of evolutionary potential and consequences. In many cases, the best strategy could be to simply maintain the ability of natural populations to respond evolutionarily on their own – rather than through direct human manipulation of evolution.

B. Direct and indirect drivers of change have accelerated during the past 50 years.

10 Today, humans extract more from the Earth and produce more waste than ever before *(well established*). Globally, land-use change is the direct driver with the largest relative impact on terrestrial and freshwater ecosystems, while direct exploitation of fish and seafood has the largest relative impact in the oceans (*well established*) (Figure SPM.2) {2.2.6.2}. Climate change, pollution and invasive alien species have had a lower relative impact to date but are accelerating (*established but incomplete*) {2.2.6.2, 3.2, 4.2}. Although the pace of agricultural expansion into intact ecosystems {2.1.13} has varied from country to country, losses of intact ecosystems have occurred primarily in the tropics, home to the highest levels of biodiversity on the planet (for example, 100 million hectares of tropical forest from 1980 to 2000), due to cattle ranching in Latin America (~42 million ha) and plantations in South-East Asia (~7.5 million hectares, 80 per cent in oil palm) among others {2.1.13}, noting that plantations can also increase total forest area. Within land-use change, urban areas have more than doubled since 1992. In terms of direct exploitation, approximately 60 billion tons[10] of renewable and non-renewable resources {2.1.2} are being extracted each year. That total has nearly doubled since 1980, as population has grown considerably while the average per capita consumption of materials (e.g., plants, animals, fossil fuels, ores, construction material) has risen by 15 per cent since 1980 *(established but incomplete)* {2.1.6, 2.1.11, 2.1.14}. This activity has generated unprecedented impacts: since 1980, greenhouse gas emissions have doubled {2.1.11, 2.1.12}, raising average global temperatures by at least 0.7 °C {2.1.12}, while plastic pollution in oceans has increased tenfold {2.1.15}. Over 80 per cent of global wastewater is being discharged back into the environment without treatment, while 300–400 million tons of heavy metals, solvents, toxic sludge and other wastes from industrial facilities are dumped into the world's waters each year {2.1.15}. Excessive or inappropriate application of fertilizer can lead to run-off from fields and enter freshwater and coastal ecosystems, producing more than 400 hypoxic zones that affected a total area of more than 245,000 km^2 as early as 2008 {2.1.15}. In some island countries, invasive alien species have a significant impact on biodiversity, with introduced species being a key driver of extinctions.

11 Land-use change is driven primarily by agriculture, forestry and urbanization, all of which are associated with air, water and soil pollution. Over one third of the world's land surface and nearly three-quarters of available freshwater resources are devoted to crop or livestock production {2.1.11}. Crop production occurs on some 12 per cent of total ice-free land. Grazing occurs on about 25 per cent of total ice-free lands and approximately 70 per cent of drylands {2.1.11}. Approximately 25 per cent of the globe's greenhouse gas emissions come from land clearing, crop production and fertilization, with animal-based food contributing 75 per cent of that. Intensive agriculture has increased food production at the cost of regulating and non-material contributions from nature, though environmentally beneficial practices are increasing. Small landholdings (less than 2 hectares) contribute approximately 30 per cent of global crop production and 30 per cent of the global food caloric supply, using around a quarter of agricultural land and usually maintaining rich agrobiodiversity {2.1.11}. Moving to logging, between 1990 and 2015, clearing and wood harvest contributed to a total reduction of 290 million hectares in native forest cover, while the area of planted forests grew by 110 million hectares {2.1.11}. Industrial roundwood harvest is falling within some developed countries but rising on average in developing countries {2.1.11}. Illegal timber harvests and related trade supply 10–15 per cent of global timber, and up to 50 per cent in certain areas, hurting revenues for state owners and livelihoods for the rural poor. All mining on land has increased dramatically and, while still using less than 1 per cent of the Earth's land, has had significant negative impacts on biodiversity, emissions of highly toxic pollutants, water quality and water distribution, and human health {2.1.11}. Mined products contribute more than 60 per cent of the GDP of 81 countries. There are approximately 17,000 large-scale mining sites in 171 countries, with the legal sites mostly managed by international corporations, but there is also extensive illegal and small-scale mining that is harder to trace, and both types of sites are often in locations relevant for biodiversity {2.1.11}.

12 In marine systems, fishing has had the most impact on biodiversity (target species, non-target species and habitats) in the past 50 years alongside other significant drivers *(well established*) {2.1.11, 2.2.6.2} (Figure SPM.2). Global fish catches have been sustained by expanding fishing geographically and penetrating into deeper waters *(well established)* {3.2.1}. An increasing proportion of marine fish stocks are overfished (33 per cent in 2015), including stocks of economically important species, while 60 per cent are maximally sustainably fished and only 7 per cent are underfished *(well established)* {Box 3.1}. Industrial fishing, concentrated in a few countries and corporations {2.1.11}, covers at least 55 per cent of the oceans, largely concentrated in the

10. All references to "tons" are to metric tons.

northeast Atlantic, the northwest Pacific and upwelling regions off South America and West Africa *(established but incomplete)* {2.1.11}. Small-scale fisheries account for more than 90 per cent of commercial fishers (over 30 million people), and nearly half of global fish catch *(established but incomplete)*. In 2011, illegal, unreported or unregulated fishing represented up to one third of the world's reported catch *(established but incomplete)* {2.1.11}. Since 1992, regional fisheries bodies have been adopting sustainable development principles. For instance, more than 170 members of the Food and Agriculture Organization of the United Nations (FAO) adopted the Code of Conduct for Responsible Fisheries in 1995, and as of 1 April 2018, 52 countries and one member organization had become Parties to the Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing, in order to address the depletion of marine fisheries *(established but incomplete)* {2.1.11}, reduce by-catch {3, box 3.3} and lower damage to seabeds and reefs. In addition, the set of established marine protected areas has been growing *(well established)* {2.1.11.1, 2.2.7.16}.

13 **The direct driver with the second highest relative impact on the oceans is the many changes in the uses of the sea and coastal land (*well established*) (Figure SPM.2) {2.2.6.2}.** Coastal habitats, including estuaries and deltas critical for marine biota and regional economies, have been severely affected by sea-use changes (coastal development, offshore aquaculture, mariculture and bottom trawling) and land-use changes (onshore land clearance and urban sprawl along coastlines, plus pollution of rivers). Pollution from land sources is already a major driver of negative environmental change. Ocean mining, while relatively small, has expanded since 1981 to ~ 6,500 offshore oil and gas installations worldwide in 53 countries (60 per cent in the Gulf of Mexico by 2003) and likely will expand into the Arctic and Antarctic regions as the ice melts {2.1.11}. Ocean acidification from increased carbon dioxide levels largely affects shallow waters, with the ecosystems of the subarctic Pacific and western Arctic Ocean particularly affected. Plastic microparticles and nanoparticles are entering food webs in poorly understood ways {2.1.15.3}. Coastal waters hold the highest levels of metals and persistent organic pollutants from industrial discharge and agricultural run-off, poisoning coastal fish harvests. Severe effects from excess nutrient concentrations in certain locations include damage to fish and seabed biota. The dynamics of ocean and airborne transport of pollutants mean that the harm from inputs of plastics, persistent organic pollutants, heavy metals and ocean acidification is felt worldwide, including with consequences for human health.

14 **Climate change is already having an impact on nature, from genes to ecosystems. It poses a growing risk owing to the accelerated pace of change and interactions with other direct drivers (*well established*) {2.1.12, 2.1.18, 2.2.6.2}**. Shifts in species distribution, changes in phenology, altered population dynamics and changes in the composition of species assemblage or the structure and function of ecosystems, are evident {2.2.5.3.2, 2.2.5.2.3, 2.2.6.2} and accelerating in marine, terrestrial and freshwater systems *(well established)* {2.2.3.2}. Almost half (47 per cent) of threatened terrestrial mammals, excluding bats, and one quarter (23 per cent) of threatened birds may have already been negatively affected by climate change in at least part of their distribution (birds in North America and Europe suggest effects of climate change in their population trends since the 1980s) *(established but incomplete)* {2.2.6.2}. Ecosystems such as tundra and taiga and regions such as Greenland, previously little affected by people directly, are increasingly experiencing the impacts of climate change *(well established)* {2.2.7.5}. Large reductions and local extinctions of populations are widespread *(well established)* {2.2.6.2}. This indicates that many species are unable to cope locally with the rapid pace of climate change, through either evolutionary or behavioural processes, and that their continued existence will also depend on the extent to which they are able to disperse, to track suitable climatic conditions, and to preserve their capacity to evolve *(well established)* {2.2.5.2.5}. Many of these changes can have significant impacts on a number of important economic sectors, and cascading effects for other components of biodiversity. Island nations, in particular those in East Asia and the Pacific region, will be most vulnerable to sea-level rise (1m) as projected by all climate change scenarios, {2.1.1.7.1} which will displace close to 40 million people {2.1.1.7.1, 2.2.7.1.8}.

15 **Unsustainable use of the Earth's resources is underpinned by a set of demographic and economic indirect drivers that have increased, and that furthermore interact in complex ways, including through trade (*well established*) {2.1.6}**. The global human population has increased from 3.7 to 7.6 billion since 1970 unevenly across countries and regions, which has strong implications for the degradation of nature. Per capita consumption also has grown, and also is unequal, with wide variations in lifestyles and access to resources across and within regions, plus consequences for nature that are distributed globally through trade. Total gross domestic product is four times higher and is rising faster in developed than in least developed countries. Approximately 821 million people face food insecurity in Asia and Africa, while 40 per cent of the global population lacks access to clean, safe drinking water. Generally, environmentally-based health burdens, such as air and water pollution, are more prevalent in least developed countries {2.1.2, 2.1.15}.

16 **Due to expansions of infrastructure, extensive areas of the planet are being opened up to new threats (*well established*) {2.1.11}**. Globally, paved road lengths are projected to increase by 25 million kilometres by

2050, with nine tenths of all road construction occurring within least developed and developing countries. The number of dams has increased rapidly in the past 50 years. Worldwide, there are now about 50,000 large dams (higher than 15 metres) and approximately 17 million reservoirs (larger than 0.01 hectares or 100m^2) {2.1.11}. The expansions of roads, cities, hydroelectric dams and oil and gas pipelines can come with high environmental and social costs, including deforestation, habitat fragmentation, biodiversity loss, land grabbing, population displacement and social disruption, including for indigenous peoples and local communities *(established but incomplete)*. Yet infrastructure can generate positive economic effects and even environmental gains, based on efficiency, innovation, migration, and urbanization, depending on where and how investment is implemented and governed *(well established)* {2.1.11}. Understanding this variation in impacts is critical.

17 Long-distance transportation of goods and people, including for tourism, have grown dramatically in the past 20 years, with negative consequences for nature overall (*established but incomplete*). The rise in airborne and seaborne transportation of both goods and people, including a threefold increase in travel from developed and developing countries in particular, has increased pollution and significantly increased the presence of invasive alien species *(well established)* {2.1.15}. Between 2009 and 2013, the carbon footprint from tourism rose 40 per cent to 4.5 gigatons of carbon dioxide, and overall, 8 per cent of total greenhouse gas emissions are from tourism-related transportation and food consumption {2.1.11, 2.1.15}. The demand for nature-based tourism or ecotourism has also risen, with mixed effects on nature and local communities, including some potential for contributions to local conservation, in particular when carried out at a smaller scale {2.1.11}.

18 Distant areas of the world are increasingly connected, as consumption, production, and governance decisions increasingly influence materials, waste, energy, and information flows in other countries, generating aggregate economic gains while shifting economic and environmental costs, which can link to conflicts (*established but incomplete*) (Figure SPM.4). As per capita consumption has risen, developed countries and rapidly growing developing countries {2.1.2, 2.1.6}, while at times supporting efficient production for exports, often reduce water consumption and forest degradation nationally {2.1.6, 2.1.11} by importing crops and other resources, mainly from developing countries {2.1.6}. The latter, as a result, see declines in nature and its contributions to people (habitat, climate, air and water quality) different from the exported food, fibre and timber products **(Figures SPM.1 and 5)**. Reduced, declining and unequal access to nature's contributions to people may, in a complex interaction with other factors, be a source of conflict within and among countries *(established but incomplete)*. Least developed countries, often rich in and more dependent upon natural resources, have suffered the greatest land degradation, have also experienced more conflict and lower economic growth, and have contributed to environmental outmigration by several million people {2.1.2, 2.1.4}. When indigenous peoples or local communities are expelled from or threatened on their lands, including by mining or industrial logging for export, this too can spark conflict – often between actors with different levels of power, as today a few actors can control large shares of any market or capital asset rivalling those of most countries {2.1.6}, while funds channelled through tax havens support most vessels implicated in illegal, unreported and unregulated fishing. More than 2,500 conflicts over fossil fuels, water, food and land are currently occurring across the planet, and at least 1,000 environmental activists and journalists were killed between 2002 and 2013 {2.1.11, 2.1.18}.

19 Governance has at many levels moved slowly to further and better incorporate into policies and incentives the values of nature's contributions to people. However, around the globe, subsidies with harmful effects on nature have persisted (*well established*) {2.1, 3, 5, 6.4}. The incorporation by society of the value of nature's contributions to people will entail shifts in governance even within private supply chains, for instance when civil society certifies and helps to reward desired practices, or when States block access to markets because of undesirable practices {2.1.7}. Successful local governance supported by recognition of local rights has often incorporated knowledge of how nature contributes to human wellbeing to motivate such behaviours {2.1.8}. National agencies have also promoted land management strategies that are more sustainable and introduced regulations, among other policy measures {2.1.9.2}, and have coordinated with other nations on global agreements to maintain nature's contributions to people {2.1.10}. Economic instruments that may be harmful to nature include subsidies, financial transfers, subsidized credit, tax abatements, and prices for commodities and industrial goods that hide environmental and social costs. Such instruments favour unsustainable production and, as a consequence, can promote deforestation, overfishing, urban sprawl, and wasteful uses of water. In 2015, agricultural support potentially harmful to nature amounted to $100 billion in countries belonging to the Organization for Economic Cooperation and Development, although some subsidy reforms to reduce unsustainable pesticide uses and adjust several other consequential development practices have been introduced {2.1.9.1, 6.4.5}. Fossil fuel subsidies valued at $345 billion result in global costs of $5 trillion when including the reduction of nature's contributions (coal accounts for about half of these costs, petroleum for about one third and natural gas for about one tenth {2.1.9.1.2}). In fisheries, subsidies to

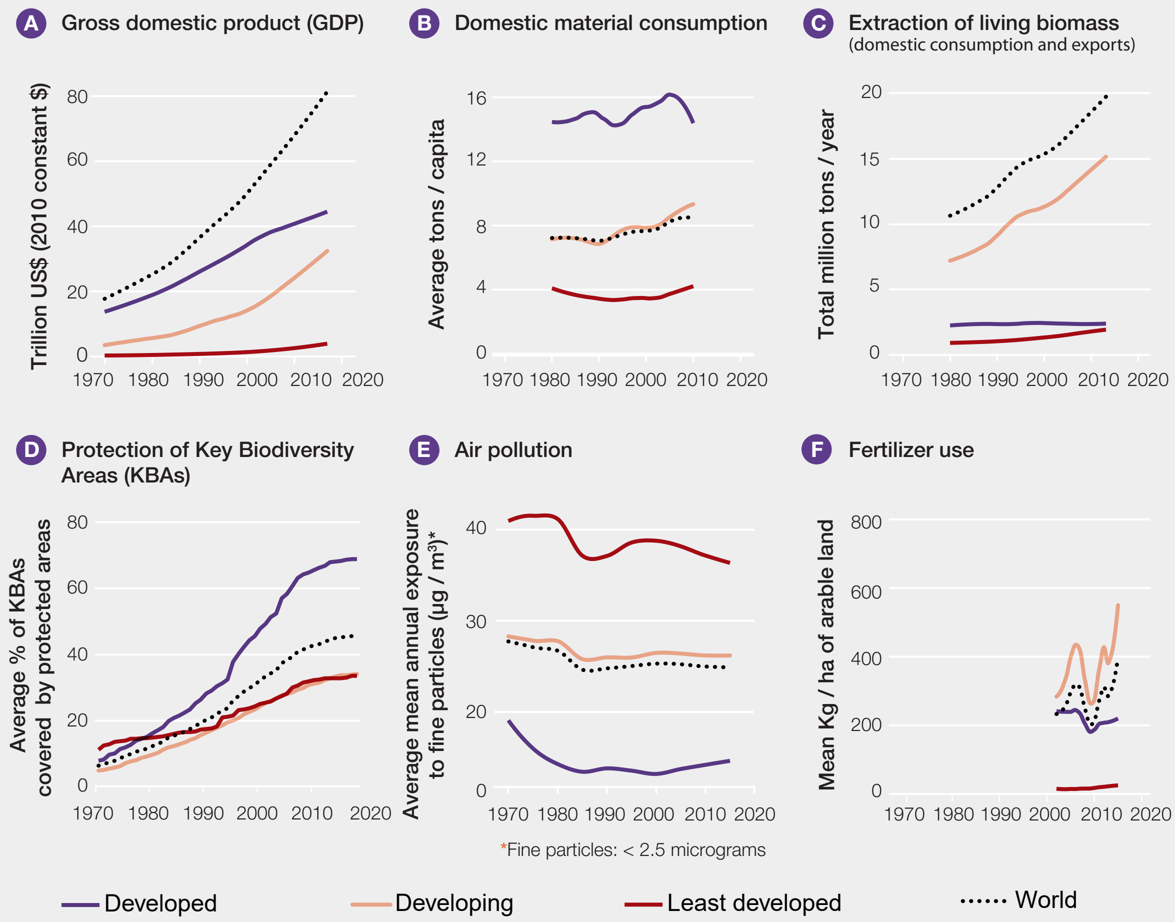

Figure SPM 4 **Development pathways since 1970 for selected key indicators of human-environment interactions, which show a large increase in the scale of global economic growth and its impacts on nature, with strong contrasts across developed, developing, and least developed countries.**

Countries are classified according to the United Nations World Economic Situation and Prospects (https://www.un.org/development/desa/dpad/publication/world-economic-situation-and-prospects-2019/). Global gross domestic product has risen fourfold in real terms, with the vast majority of growth occurring in developed and developing countries A. Extraction of living biomass (e.g., crops, fish) to meet the demand for domestic consumption and for export is highest in developing countries and rising rapidly B. However, material consumption per capita within each country (from imports and domestic production) is highest in developed countries. Overall protection of Key Biodiversity Areas is rising, being highest within developed countries D. Air pollution is highest in least developed countries E, while the challenges of non-point-source pollution from the use of fertilizers are highest in developing countries. Data sources: A, E, F: www.data.worldbank.org; B, C: www.materialflows.net; D: www.keybiodiversityareas.org, www.protectedplanet.net.

increase and maintain capacity, which in turn often lead to the degradation of nature, constitute perhaps a majority of the tens of US$ billions spent on supports {5.3.2.5}.

20 Much of the world's terrestrial wild and domesticated biodiversity lies in areas traditionally managed, owned, used or occupied by indigenous peoples and local communities (*well established*) (Figure SPM.5) {2.2.4}. In spite of efforts at all levels, although nature on indigenous lands is declining less rapidly than elsewhere, biodiversity and the knowledge associated with its management are still deteriorating (*established but incomplete*) {2.2.4, 2.2.5.3}. Despite a long history of resource use, conservation conflicts related to colonial expansion and land appropriation for parks and other uses {3.2} *(well established)*, indigenous peoples and local communities have often managed their landscapes and seascapes in ways that were adjusted to local conditions over generations. These management methods often remain compatible with, or actively support, biodiversity conservation by "accompanying" natural processes with anthropogenic assets *(established but incomplete)* {2.2.4, 2.2.5.3.1} **(Figure SPM.5)**.

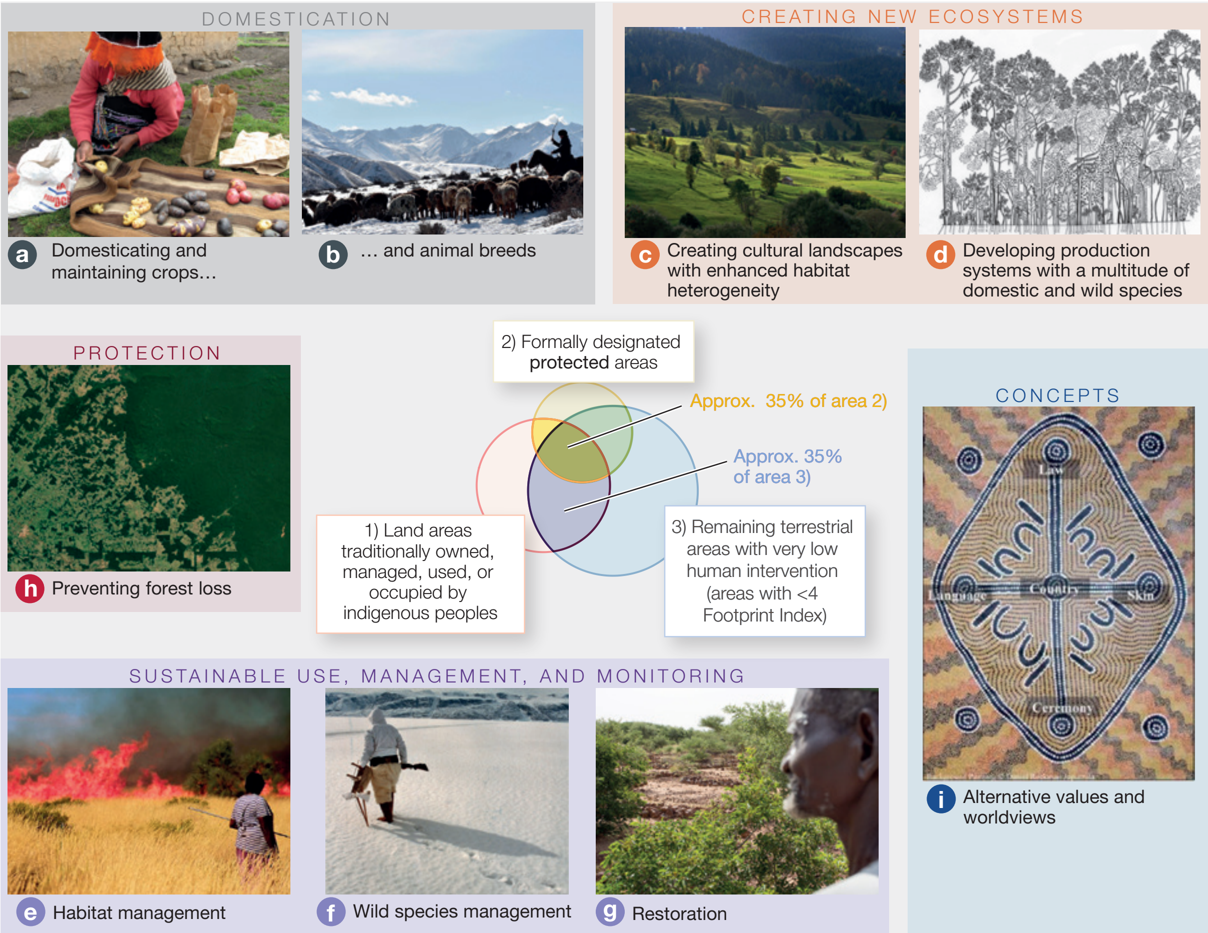

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Figure SPM 5 **Contributions of indigenous peoples and local communities to the enhancement and maintenance of wild and domesticated biodiversity and landscapes. Indigenous and local knowledge systems are locally based, but regionally manifested and thus globally relevant.**

A wide diversity of practices actively and positively contributes to wild and domestic biodiversity through "accompanying" natural processes with anthropogenic assets (knowledge, practices and technology). Indigenous peoples often manage the land and coastal areas based on culturally specific world views, applying principles and indicators such as the health of the land, caring for the country and reciprocal responsibility. As lifestyles, values and external pressures change with globalization, however, unsustainable practices are becoming increasingly common in certain regions[11]. The image in the centre of the above figure shows the global overlap between 1) land areas traditionally owned, managed[11], used, or occupied by indigenous peoples; 2) formally designated protected areas; and 3) remaining terrestrial areas with very low human intervention (areas that score <4 on the Human Footprint Index[12]). Circles and overlapping sections are proportional in area. Land areas traditionally owned, managed[13], used, or occupied by indigenous peoples overlap with approximately 35 per cent of the area that is formally protected, and approximately 35 per cent of all remaining terrestrial areas with very low human intervention. The topics and pictures in the figure aim to illustrate, not represent, the types and diversity of the following contributions of indigenous peoples and local communities to biodiversity: a domestication and maintenance of locally adapted crop and fruit varieties (potatoes, Peru) and b animal breeds (rider and sheep, Kyrgyzstan) {2.2.4.4}; c creation of species-rich habitats and high ecosystem diversity in cultural landscapes (hay meadows, Central Europe) {2.2.4.1-2}; d identification of useful plants and their cultivation in high-diversity ecosystems (multi-species forest garden, Indonesia) {2.2.4.3}; e and f management and monitoring of wild species, habitats and landscapes for wildlife and for increased resilience (e - Australia, f - Alaska) {2.2.4.5-6}; g restoration of degraded lands (Niger) {3.2.4}; h prevention of deforestation in recognized indigenous territories (Amazon basin, Brazil) {2.2.4.7}; i offering alternative concepts of relations between humanity and nature (Northern Australia).

11. In Stephen Garnett *et al.*, "A spatial overview of the global importance of Indigenous lands for conservation", *Nature Sustainability*, Vol. 1 (July 2018) pp. 369–374.

12. These data sources define land management here as the process of determining the use, development and care of land resources in a manner that fulfils material and non-material cultural needs, including livelihood activities such as hunting, fishing, gathering, resource harvesting, pastoralism, and small-scale agriculture and horticulture.

13. Venter, O. *et al.* Global terrestrial Human Footprint maps for 1993 and 2009. Sci. Data 3, sdata201667 (2016).

At least one quarter of the global land area is traditionally managed[14], owned, used or occupied by indigenous peoples. These areas include approximately 35 per cent of the area that is formally protected, and approximately 35 per cent of all remaining terrestrial areas with very low human intervention *(established but incomplete)* {2.2.5.3.1}. Community-based conservation institutions and local governance regimes have often been effective, at times even more effective than formally established protected areas, in preventing habitat loss *(established but incomplete)*. Several studies have highlighted contributions by indigenous peoples and local communities in limiting deforestation, as well as initiatives showing synergies between these different mechanisms *(well established)* {6.3.2, 2.2.5.3}. In many regions, however, the lands of indigenous peoples are becoming islands of biological and cultural diversity surrounded by areas in which nature has further deteriorated *(established but incomplete)* {2.2.5.3}. Among the local indicators developed and used by indigenous peoples and local communities, 72 per cent show negative trends in nature that underpinned local livelihoods *(established but incomplete)* {2.2.5.3.2}. Major trends include declining availability of resources – due in part to legal and illegal territory reductions, despite expanding indigenous populations – as well as declining health and populations of culturally important species; new pests and invasive alien species as climate changes; losses in both natural forest habitats and grazing lands; and declining productivity in remnant ecosystems. A more detailed global synthesis of trends in nature observed by indigenous peoples and local communities is hindered by the lack of institutions that gather data for these locations and then synthesize them within regional and global summaries {2.2.2}.

14. These data sources define land management here as the process of determining the use, development and care of land resources in a manner that fulfils material and non-material cultural needs, including livelihood activities such as hunting, fishing, gathering, resource harvesting, pastoralism, and small-scale agriculture and horticulture.

C. Goals for conserving and sustainably using nature and achieving sustainability cannot be met by current trajectories, and goals for 2030 and beyond may only be achieved through transformative changes[15] across economic, social, political and technological factors.

21 There has been good progress towards the components of 4 of the 20 Aichi Biodiversity Targets under the Strategic Plan for Biodiversity 2011–2020. Moderate progress has been achieved towards some components of 7 more targets, but for 6 others, poor progress has been made towards all components. There is insufficient information to assess progress towards some or all components of the remaining 3 targets (*established but incomplete*) {3.2}. Overall, the state of nature continues to decline (12 of 16 indicators show significantly worsening trends) (*well established*) {3.2} (Figure SPM.6).

By 2015, greater progress had been made in implementing policy responses and actions to conserve biodiversity for drivers with an impact on coral reefs and other ecosystems vulnerable to climate change (*established but incomplete*) *{3.2}.* Anthropogenic drivers of biodiversity loss, including habitat loss as a result of land-use and sea use change (addressed by Aichi Target 5), unsustainable agriculture, aquaculture and forestry (Aichi Target 7), unsustainable fishing (Aichi Target 6), pollution (Aichi Target 8), and invasive alien species (Aichi Target 9) are increasing globally, despite national efforts to meet the Aichi Targets *(established but incomplete)* {3.2}.

15. A fundamental, system-wide reorganization across technological, economic and social factors, including paradigms, goals and values.

22 Conservation actions, including protected areas, efforts to manage unsustainable use and address the illegal capture and trade of species, and the translocation and eradication of invasive species, have been successful in preventing the extinction of some species (*established but incomplete*). For example, conservation investment during the period between 1996 and 2008 reduced the extinction risk for mammals and birds in 109 countries by a median value of 29 per cent per country, while the rate of decrease in extinction risk for birds, mammals and amphibians would have been at least 20 per cent higher without conservation action in recent decades. Similarly, it is likely that at least 6 species of ungulate (e.g., the Arabian Oryx and Przewalski's Horse) would now be extinct or surviving only in captivity without conservation measures. At least 107 highly threatened birds, mammals and reptiles (e.g., the Island Fox and the Seychelles Magpie-Robin) are estimated to have benefited from invasive mammal eradication on islands {3.2.2}. Although still few and spatially localized, such cases show that with prompt and appropriate action, it is possible to reduce human-induced extinction rates

Goal	Target	Target element (abbreviated)	Progress towards the Aichi Targets		
			Poor	Moderate	Good
A. Address the underlying drivers	1	1.1 Awareness of biodiversity		■	
		1.2 Awareness of steps to conserve		■	
	2	2.1 Biodiversity integrated into poverty reduction		■	
		2.2 Biodiversity integrated into planning		■	
		2.3 Biodiversity integrated into accounting	■		
		2.4 Biodiversity integrated into reporting	■		
	3	3.1 Harmful subsidies eliminated and reformed	■		
		3.2 Positive incentives developed and implemented	■		
	4	4.1 Sustainable production and consumption	■		
		4.2 Use within safe ecological limits	■		
B. Reduce direct pressures	5	5.1 Habitat loss at least halved	■		
		5.2 Degradation and fragmentation reduced	■		
	6	6.1 Fish stocks harvested sustainably	■		
		6.2 Recovery plans for depleted species	Unknown		
		6.3 Fisheries have no adverse impact	■		
	7	7.1 Agriculture is sustainable	■		
		7.2 Aquaculture is sustainable	■		
		7.3 Forestry is sustainable		■	
	8	8.1 Pollution not detrimental	■		
		8.2 Excess nutrients not detrimental	■		
	9	9.1 Invasive alien species prioritized			■
		9.2 Invasive alien pathways prioritized	Unknown		
		9.3 Invasive species controlled or eradicated	■		
		9.4 Invasive introduction pathways managed	■		
	10	10.1 Pressures on coral reefs minimized	■		
		10.2 Pressures on vulnerable ecosystems minimized	■		
C. Improve biodiversity status	11	11.1 10 per cent of marine areas conserved			■
		11.2 17 per cent of terrestrial areas conserved			■
		11.3 Areas of importance conserved		■	
		11.4 Protected areas, ecologically representative		■	
		11.5 Protected areas, effectively and equitably managed		■	
		11.6 Protected areas, well-connected and integrated		■	
	12	12.1 Extinctions prevented	■		
		12.2 Conservation status of threatened species improved	■		
	13	13.1 Genetic diversity of cultivated plants maintained		■	
		13.2 Genetic diversity of farmed animals maintained		■	
		13.3 Genetic diversity of wild relatives maintained		■	
		13.4 Genetic diversity of valuable species maintained	Unknown		
		13.5 Genetic erosion minimized		■	
D. Enhance benefits to all	14	14.1 Ecosystems providing services restored and safeguarded	■		
		14.2 Taking account of women, IPLCs, and other groups	Unknown		
	15	15.1 Ecosystem resilience enhanced	Unknown		
		15.2 15 per cent of degraded ecosystems restored	Unknown		
	16	16.1 Nagoya Protocol in force			■
		16.2 Nagoya Protocol operational		■	
E. Enhance implementation	17	17.1 NBSAPs developed and updated			■
		17.2 NBSAPs adopted as policy instruments		■	
		17.3 NBSAPs implemented		■	
	18	18.1 ILK and customary use respected		■	
		18.2 ILK and customary use integrated	Unknown		
		18.3 IPLCs participate effectively	Unknown		
	19	19.1 Biodiversity science improved and shared		■	
		19.2 Biodiversity science applied	Unknown		
	20	20.1 Financial resources for Strategic Plan[a] increased		■	

Abbreviations: ILK: indigenous and local knowledge; IPLCs: indigenous peoples and local communities; NBSAPs: national biodiversity strategies and action plans.
[a] Strategic Plan for Biodiversity 2011–2020.

Figure SPM 6 **Summary of progress towards the Aichi Targets.**

Scores are based on a quantitative analysis of indicators, a systematic review of the literature, the fifth National Reports to the Convention on Biological Diversity and the information available on countries' stated intentions to implement additional actions by 2020. Progress towards target elements is scored as "Good" (substantial positive trends at a global scale relating to most aspects of the element); "Moderate" (the overall global trend is positive, but insubstantial or insufficient, or there may be substantial positive trends for some aspects of the element, but little or no progress for others; or the trends are positive in some geographic regions, but not in others); "Poor" (little or no progress towards the element or movement away from it; or, despite local, national or case-specific successes and positive trends for some aspects, the overall global trend shows little or negative progress); or "Unknown" (insufficient information to score progress).

(established but incomplete) {2.2.5.2.4, 4}. There are, however, few other counterfactual studies assessing how trends in the state of nature or pressures upon nature would have been different in the absence of conservation efforts *(well established)* {3.2}.

23 **Biodiversity and ecosystem functions and services directly underpin the achievement of several of the Sustainable Development Goals, including those on water and sanitation, climate action, life below water and life on land (Sustainable Development Goals 6, 13, 14 and 15), *(well established)* {3.3.2.1}. Nature also plays an important and complex role in the achievement of the Sustainable Development Goals related to poverty, hunger, health and well-being and sustainable cities (Sustainable Development Goals 1, 2, 3 and 11) *(established but incomplete)* {3.3.2.2} (Figure SPM.7).** Several examples illustrate the interdependencies between nature and the Sustainable Development Goals. For example, nature and its contributions may play an important role in reducing vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters, although anthropogenic assets are also involved *(established but incomplete)*. Nature's underpinning of specific health targets varies across regions and ecosystems, is influenced by anthropogenic assets and remains understudied. The relationship can be positive or negative, as in the case of certain aspects of biodiversity and infectious diseases (see paragraph 2 of the present document). Nature directly underpins the livelihoods of indigenous peoples and local communities and the rural and urban poor, largely through direct consumption or through the income generated by trade in material contributions such as food (see paragraphs 2 and 36 of the present document) and energy *(well established)*. Such contributions are generally underrepresented in poverty analyses *(established but incomplete)*. Nature and its contributions are also relevant to the Goals for education, gender equality, reducing inequalities and promoting peace, justice and strong institutions (Sustainable Development Goals 4, 5, 10 and 16), but the current focus and wording of the related targets obscures or omits their relationship to nature *(established but incomplete)*.

24 **To achieve the Sustainable Development Goals and the 2050 Vision for Biodiversity, future targets are likely to be more effective if they take into account the impacts of climate change *(well established)* {3.2, 3.3}.** For example, climate change is projected to greatly increase the number of species under threat, with fewer species expanding their ranges or experiencing more suitable climatic conditions than the number of species experiencing range contraction or less suitable conditions *(established but incomplete)* {4.2, 3.2}. The impact of climate change on the effectiveness of protected areas calls for a re-evaluation of conservation objectives; meanwhile, there are currently few protected areas whose objectives and management take climate change into account *(established but incomplete)*. The Sustainable Development Goals for poverty, health, water and food security, and sustainability targets are closely linked through the impacts of multiple direct drivers, including climate change, on biodiversity and ecosystem functions and services, nature and nature's contributions to people and good quality of life. In a post-2020 global biodiversity framework, placing greater emphasis on the interactions between the targets of the Sustainable Development Goals {4.6, 3.7} may provide a way forward for achieving multiple targets, as synergies (and trade-offs) can be considered. Future targets are expected to be more effective if they take into account the impacts of climate change, including on biodiversity, and action to mitigate and adapt to climate change {4.6, 3.7}.

25 **The adverse impacts of climate change on biodiversity are projected to increase with increasing warming, so limiting global warming to well below 2°C would have multiple co-benefits for nature and nature's contributions to people and quality of life; however, it is projected that some large-scale land-based mitigation measures to achieve that objective will have significant impacts on biodiversity *(established but***

Selected Sustainable Development Goals	Selected targets (abbreviated)	Recent status and trends in aspects of nature and nature's contributions to people that support progress towards target *		Uncertain relationship
		Poor/Declining support	Partial support	
No poverty	1.1 Eradicate extreme poverty			U
	1.2 Halve the proportion of people in poverty			U
	1.4 Ensure that all have equal rights to economic resources	■		
	1.5 Build the resilience of the poor	■		
Zero hunger	2.1 End hunger and ensure access to food all year round		■	
	2.3 Double productivity and incomes of small-scale food producers		■	
	2.4 Ensure sustainable food production systems	■		
	2.5 Maintain genetic diversity of cultivated plants and farmed animals		■	
Good health and well-being	3.2 End preventable deaths of newborns and children			U
	3.3 End AIDS, tuberculosis, malaria and neglected tropical diseases			U
	3.4 Reduce premature mortality from non-communicable diseases	Unknown		
	3.9 Reduce deaths and illnesses from pollution	Unknown		
Clean water and sanitation	6.3 Improve water quality	■		
	6.4 Increase water use and ensure sustainable withdrawals	■		
	6.5 Implement integrated water resource management		■	
	6.6 Protect and restore water-related ecosystems	■		
Sustainable cities and communities	11.3 Enhance inclusive and sustainable urbanization	■		
	11.4 Protect and safeguard cultural and natural heritage		■	
	11.5 Reduce deaths and the number of people affected by disasters	■		
	11.6 Reduce the adverse environmental impact of cities	■		
	11.7 Provide universal access to green and public spaces	■		
Climate action	13.1 Strengthen resilience to climate-related hazards	■		
	13.2 Integrate climate change into policies, strategies and planning		■	
	13.3 Improve education and capacity on mitigation and adaptation	Unknown		
	13a Mobilize US$100 billion/year for mitigation by developing countries	Unknown		
	13b Raise capacity for climate change planning and management	Unknown		
Life below water	14.1 Prevent and reduce marine pollution	■		
	14.2 Sustainably manage and protect marine and coastal ecosystems		■	
	14.3 Minimize and address ocean acidification	■		
	14.4 Regulate harvesting and end overfishing		■	
	14.5 Conserve at least 10 per cent of coastal and marine areas		■	
	14.6 Prohibit subsidies contributing to overfishing	■		
	14.7 Increase economic benefits from sustainable use of marine resources	■		
Life on land	15.1 Ensure conservation of terrestrial and freshwater ecosystems	■		
	15.2 Sustainably manage and restore degraded forests and halt deforestation	■		
	15.3 Combat desertification and restore degraded land	■		
	15.4 Conserve mountain ecosystems		■	
	15.5 Reduce degradation of natural habitats and prevent extinctions	■		
	15.6 Promote fair sharing of benefits from use of genetic resources		■	
	15.7 End poaching and trafficking	■		
	15.8 Prevent introduction and reduce impact of invasive alien species	■		
	15.9 Integrate biodiversity values into planning and poverty reduction		■	
	15a Increase financial resources to conserve and sustainably use biodiversity		■	
	15b Mobilize resources for sustainable forest management		■	

* There were no targets that were scored as good/positive status and trends

Figure SPM 7 **Summary of recent status and trends in aspects of nature and nature's contributions to people that support progress towards achieving selected targets of the Sustainable Development Goals.**

The targets selected are those where the current evidence and wording of the target make it possible to assess the consequences of the trends in nature and nature's contribution to people as they relate to the achievement of the target. Chapter 3, Section 3.3 provides an assessment of the evidence of the links between nature and the Sustainable Development Goals. The scores for the targets are based on a systematic assessment of the literature and a quantitative analysis of the indicators, where possible. None of the targets scored "Full support" (that is, having a good status or substantial positive trends on a global scale). Consequently, the score of "Full support" was not included in the table. "Partial support" means that the overall global status and trends are positive, but still insubstantial or insufficient; or there may be substantial positive trends for some relevant aspects, but negative trends for others; or the trends are positive in some geographic regions, but negative in others. "Poor/Declining support" indicates poor status or substantial negative trends at a global scale. "Uncertain relationship" means that the relationship between nature and/or nature's contributions to people and the achievement of the target is uncertain. "Unknown" indicates that there is insufficient information to score the status and trends.

***incomplete)* {4.2, 4.3, 4.4, 4.5}.** All climate model trajectories show that limiting human-induced climate change to well below 2°C requires immediate, rapid reductions in greenhouse gas emissions or a reliance on substantial carbon dioxide removal from the atmosphere. However, the land areas required for bioenergy crops (with or without carbon capture and storage), afforestation and reforestation to achieve the targeted carbon uptake rates are projected to be very large {4.2.4.3., 4.5.3}. The biodiversity and environmental impact of large-scale afforestation and reforestation depends to a large degree on where these occur (prior vegetation cover, state of degradation), and the tree species planted *(established but incomplete)*. Likewise, large bioenergy crop or afforested areas are expected to compete with areas set aside for conservation, including restoration, or agriculture *(established but incomplete)*. Consequently, large-scale land-based mitigation measures may jeopardize the achievement of other Sustainable Development Goals that depend on land resources *(well established)* {4.5.3}. In contrast, the benefits of avoiding and reducing deforestation and promoting restoration can be significant for biodiversity *(well established)* and are expected to have co-benefits for local communities *(established but incomplete)* {4.2.4.3}.

26 Biodiversity and nature's regulating contributions to people are projected to decline further in most scenarios of global change over the coming decades, while the supply and demand for nature's material contributions to people that have current market value (food, feed, timber and bioenergy) are projected to increase (*well established*) {4.2, 4.3} (for example, see **Figure SPM.8**). These changes arise from continued human population growth, increasing purchasing power, and increasing per capita consumption. The projected effects of climate change and land use change on terrestrial and freshwater biodiversity are mostly negative, increase with the degree of global warming and land use change, and have an impact on marine biodiversity through increased eutrophication and deoxygenation of coastal waters *(well established)* {4.2.2.3.2, 4.2.3, 4.2.4}. For instance, a synthesis of many studies estimates that the fraction of species at risk of extinction due to climate change is 5 per cent at 2°C warming, rising to 16 per cent at 4.3°C warming {4.2.1.1}. Climate change and business-as-usual fishing scenarios are expected to worsen the status of marine biodiversity *(well established)* {4.2.2.2, 4.2.2.3.1}. Climate change alone is projected to decrease ocean net primary production by between 3 and 10 per cent, and fish biomass by between 3 and 25 per cent (in low and high warming scenarios, respectively) by the end of the century *(established but incomplete)* {4.2.2.2.1}. Whether or not the current removal of nearly 30 per cent of anthropogenic carbon dioxide emissions by terrestrial ecosystems continues into the future varies greatly from one scenario to the next and depends heavily on how climate change, atmospheric carbon dioxide and land-use change interact. Important regulating contributions of nature, such as coastal and soil protection, crop pollination and carbon storage, are projected to decline *(established but incomplete)* {4.2.4, 4.3.2.1}. In contrast, substantial increases in food, feed, timber and bioenergy production are predicted in most scenarios *(well established)* {4.2.4, 4.3.2.2}. Scenarios that include substantial shifts towards sustainable management of resource exploitation and land use, market reform, globally equitable and moderate animal protein consumption, and reduction of food waste and losses result in low loss or even recovery of biodiversity *(well established)* {4.2.2.3.1, 4.2.4.2, 4.3.2.2, 4.5.3}.

27 The magnitude of the impacts on biodiversity and ecosystem functions and services and the differences between regions are smaller in scenarios that focus on global or regional sustainability (*well established*) (Figure SPM.8). Sustainability scenarios that explore moderate and equitable consumption result in substantially lower negative impacts on biodiversity and ecosystems due to food, feed and timber production *(well established)* {4.1.3, 4.2.4.2, 4.3.2, 4.5.3}. The general patterns at the global level – namely, declines in biodiversity and regulating contributions versus increases in the production of food, bioenergy and materials – are evident in nearly all subregions {4.2.2, 4.2.3, 4.2.4, 4.3.3}. For terrestrial systems, most studies indicate that South America, Africa and parts of Asia will be much more significantly affected than other regions, especially in scenarios that are not based on sustainability objectives (see **Figure SPM.8** as an example). That is due in part to regional climate change differences and in part to the fact that scenarios generally foresee the largest land use conversions to crops or bioenergy in those regions {4.1.5, 4.2.4.2}. Regions such as North America and Europe are expected to have low conversion to crops and continued reforestation {4.1.5, 4.2.4.2}.

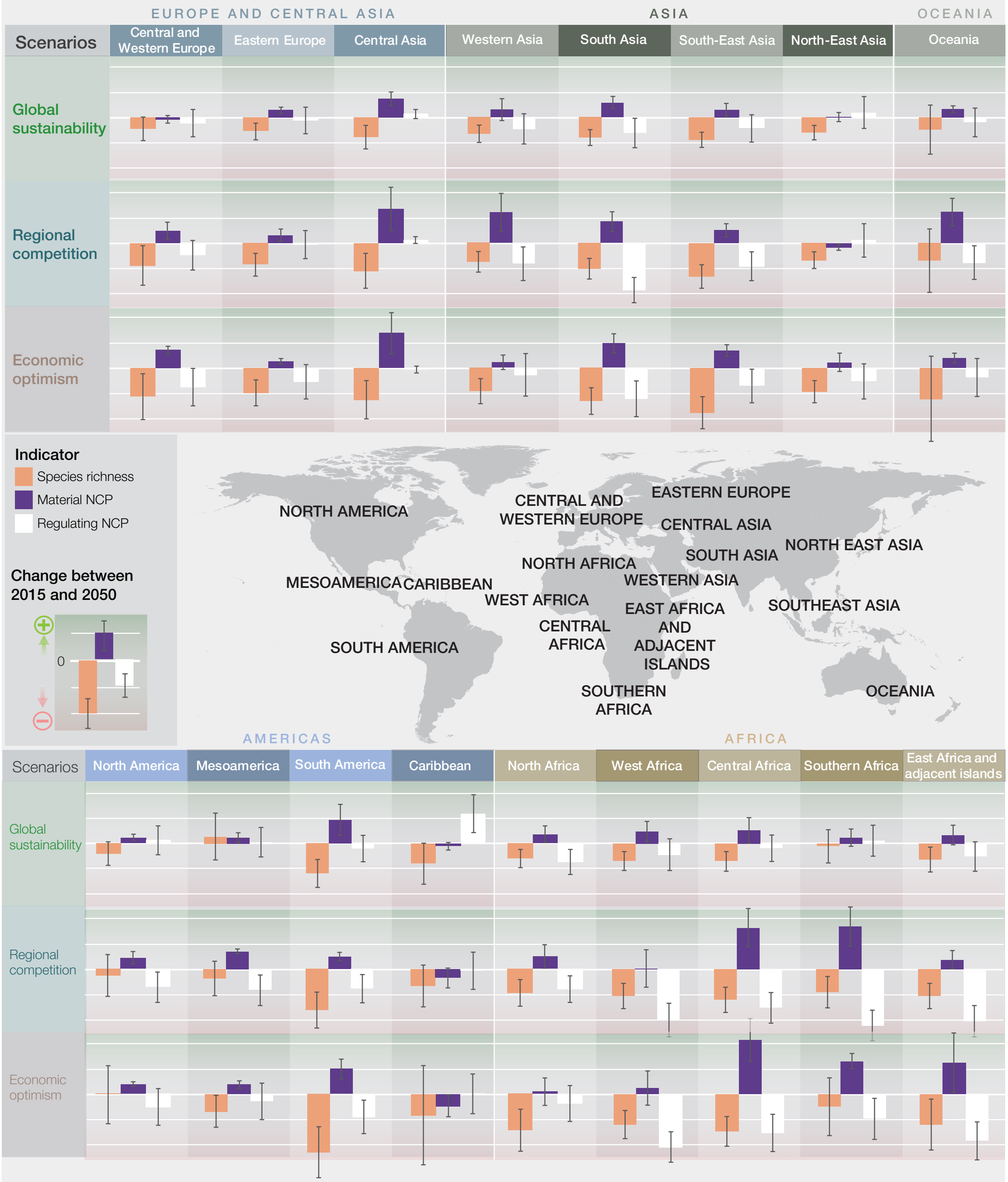

Figure SPM 8 **Projections of the impacts of land use and climate change on biodiversity and nature's material and regulating contributions to people between 2015 and 2050.**

This figure illustrates three main messages: i) the impacts on biodiversity and on nature's contributions to people (NCP) are the lowest in the "global sustainability" scenario in nearly all sub-regions, ii) regional differences in impacts are high in the regional competition and economic optimism scenario, and iii) material NCP increase the most in the regional competition and economic optimism scenarios, but this comes at the expense of biodiversity and regulating NCP. Projected impacts are based on a subset of the Shared Socioeconomic Pathway (SSP) scenarios and greenhouse gas emissions trajectories (RCP) developed in support of Intergovernmental Panel on Climate Change assessments. This figure does not cover the scenarios that include transformative change that are discussed in Chapter 5.

- The **"Global sustainability"** scenario combines proactive environmental policy and sustainable production and consumption with low greenhouse gas emissions (SSP1, RCP2.6; top rows in each panel);
- The **"Regional competition"** scenario combines strong trade and other barriers and a growing gap between rich and poor with high emissions (SSP3, RCP6.0; middle rows); and
- The **"Economic optimism"** scenario combines rapid economic growth and low environmental regulation with very high greenhouse emissions (SSP5, RCP8.5; bottom rows).

Multiple models were used with each of the scenarios to generate the first rigorous global-scale model comparison estimating the impact on biodiversity (change in species richness across a wide range of terrestrial plant and animal species at regional scales; orange bars), material NCP (food, feed, timber and bioenergy: purple bars) and regulating NCP (nitrogen retention, soil protection, crop pollination, crop pest control and ecosystem carbon storage and sequestration: white bars). The bars represent the normalized means of multiple models and the whiskers indicate the standard errors. The global means of percentage changes in individual indicators can be found in Figure 4.2.14.

28 **Climate change impacts also play a major role in regionally-differentiated projections of biodiversity and ecosystem functioning in both marine and terrestrial systems. Novel communities, where species will co-occur in historically unknown combinations, are expected to emerge (*established but incomplete*) {4.2.1.2, 4.2.4.1}** Substantial climate change-driven shifts of terrestrial biome boundaries, in particular in boreal, subpolar and polar regions and in (semi-) arid environments, are projected for the coming decades; a warmer, drier climate will reduce productivity in many places *(well established)* {4.2.4.1}. In contrast, rising atmospheric carbon dioxide concentrations can be beneficial for net primary productivity and can enhance woody vegetation cover, especially in semi-arid regions *(established but incomplete)* {4.2.4.1}. For marine systems, impacts are expected to be geographically variable, with many fish populations projected to move poleward due to ocean warming, meaning that local species extinctions are expected in the tropics *(well established)* {4.2.2.2.1}. However, that does not necessarily imply an increase in biodiversity in the polar seas, because of the rapid rate of sea ice retreat and the enhanced ocean acidification of cold waters *(established but incomplete)* {4.2.2.2.4}. Along coastlines, the upsurge in extreme climatic events, sea level rise and coastal development are expected to cause increased fragmentation and loss of habitats. Coral reefs are projected to undergo more frequent extreme warming events, with less recovery time in between, declining by a further 70–90 per cent at global warming of 1.5°C, and by more than 99 per cent at warming of 2°C, causing massive bleaching episodes with high coral mortality rates *(well established)* {4.2.2.2.2}.

D. Nature can be conserved, restored and used sustainably while simultaneously meeting other global societal goals through urgent and concerted efforts fostering transformative change.

29 **The Sustainable Development Goals and the 2050 Vision for Biodiversity cannot be achieved without transformative change, the conditions for which can be put in place now (*well established*) {2, 3, 5, 6.2} (Figure SPM.9)**. Increasing awareness of interconnectedness in the context of the environmental crisis and new norms regarding interactions between humans and nature would support that change *(well established)* {5.3, 5.4.3}. In the short term (before 2030), all decision makers could contribute to sustainability transformations, including through enhanced and improved implementation and enforcement of effective existing policy instruments and regulations, and the reform and removal of harmful existing policies and subsidies *(well established)*. Additional measures are necessary to enable transformative change over the long term (up to 2050) to address the indirect drivers that are the root causes of the deterioration of nature *(well established)*, including changes in social, economic and technological structures within and across nations {6.2, 6.3, 6.4} **(SPM Table.1)**.

30 **Sustainability transformations call for cross-sectoral thinking and approaches (Figure SPM.9). Sectoral policies and measures can be effective in particular contexts, but often fail to account for indirect, distant and cumulative impacts, which can have adverse effects, including the exacerbation of inequalities (*well established*).** Cross-sectoral

approaches, including landscape approaches, integrated watershed and coastal zone management, marine spatial planning, bioregional scale planning for energy, and new urban planning paradigms offer opportunities to reconcile multiple interests, values and forms of resource use, provided that these cross-sectoral approaches recognize trade-offs and uneven power relations between stakeholders *(established but incomplete)* {5.4.2, 5.4.3, 6.3, 6.4}.

31 **Transformative change is facilitated by innovative governance approaches that incorporate existing approaches, such as integrative, inclusive, informed and adaptive governance. While such approaches have been extensively practised and studied separately, it is increasingly recognized that together, they can contribute to transformative change (*established but incomplete*) {6.2}.** They help to address governance challenges that are common to many sectors and policy domains and create the conditions for implementing transformative change. Integrative approaches, such as mainstreaming across government sectors, are focused on the relationships between sectors and policies and help to ensure policy coherence and effectiveness *(well established)*. Inclusive approaches help to reflect a plurality of values and ensure equity *(established but incomplete)*, including through equitable sharing of benefits arising from their use and rights-based approaches *(established but incomplete)*. Informed governance entails novel strategies for knowledge production and co-production that are inclusive of diverse values and knowledge systems *(established but incomplete)*. Adaptive approaches, including learning from experience, monitoring and feedback loops, contribute to preparing for and managing the inevitable uncertainties and complexities associated with social and environmental changes *(established but incomplete)* {6.2, 5.4.2}.

32 **A summary of the evidence related to the components of pathways to sustainability suggests that there are five overarching types of management**

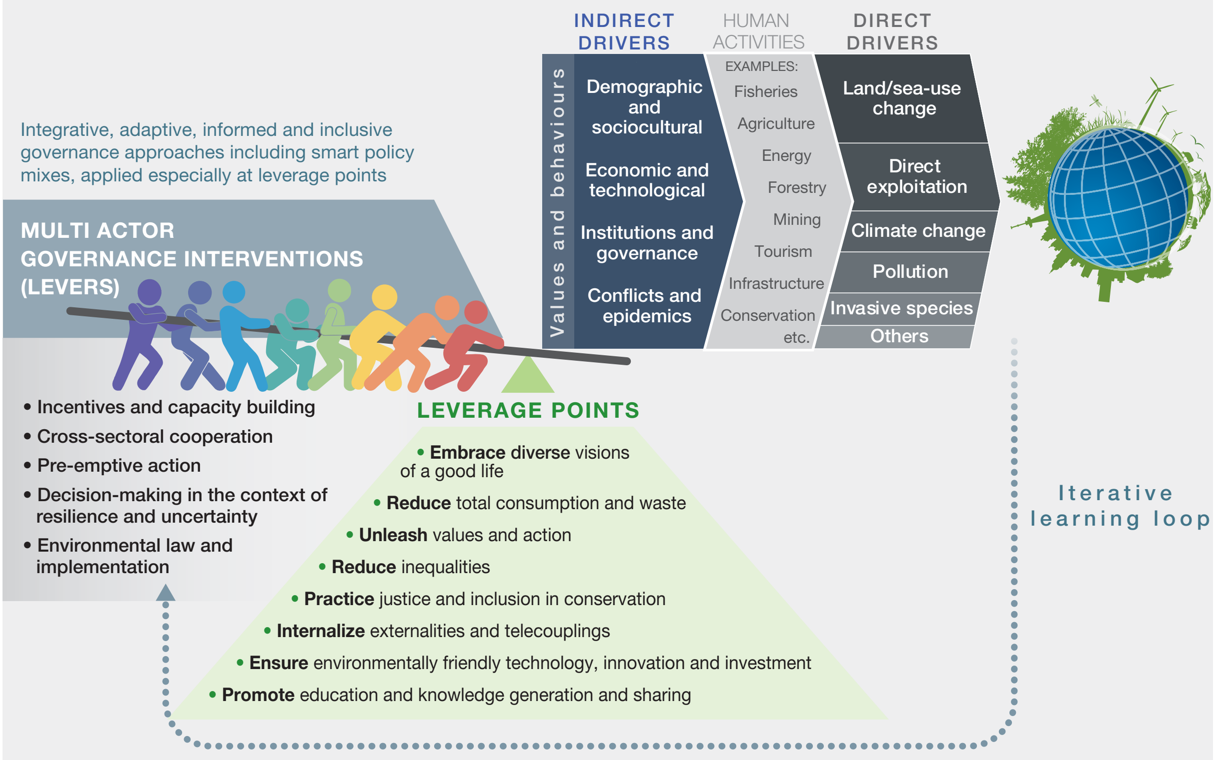

Figure SPM 9 **Transformative change in global sustainability pathways.**

Collaborative implementation of priority governance interventions (levers) targeting key points of intervention (leverage points) could enable transformative change from current trends towards more sustainable ones. Most levers can be applied at multiple leverage points by a range of actors, such as intergovernmental organizations, governments, non-governmental organizations, citizen and community groups, indigenous peoples and local communities, donor agencies, science and educational organizations, and the private sector, depending on the context. Implementing existing and new instruments through place-based governance interventions that are integrative, informed, inclusive and adaptive, using strategic policy mixes and learning from feedback, could enable global transformation.

interventions, or levers, and eight leverage points that are key for achieving transformative change (**Figure SPM.9**; D3 and D4 above) {5.4.1, 5.4.2}. The notion of levers and leverage points recognizes that complex global systems cannot be managed simply, but that in certain cases, specific interventions can be mutually reinforcing and can generate larger-scale changes towards achieving shared goals *(well established)* **(Table SPM.1)**. For example, changes in laws and policies can enable and underpin changes in resource management and consumption, and in turn, changes in individual and collective behaviour and habits can facilitate the implementation of policies and laws {5.4.3}.

33 **Changes towards sustainable production and consumption and towards reducing and transforming residues and waste, particularly changes in consumption among the affluent, is recognized by some individuals and communities worldwide as central to sustainable development and reducing inequalities. While actual reductions have been limited, actions already being taken at different levels can be improved, coordinated and scaled up *(well established).*** Those include introducing and improving standards, systems and relevant regulations aimed at internalizing the external costs of production, extraction and consumption (such as pricing wasteful or polluting practices, including through penalties); promoting resource efficiency and circular and other economic models; voluntary environmental and social certification of market chains; and incentives that promote sustainable practices and innovation. Importantly, they also involve a change in the definition of what a good quality of life entails – decoupling the idea of a good and meaningful life from ever-increasing material consumption. All those approaches are more effective when they are mutually reinforcing. Actions that help to voluntarily unleash existing social values of responsibility in the form of individual, collective and organizational actions towards sustainability can have a powerful and lasting effect in shifting behaviour and cultivating stewardship as a normal social practice *(established but incomplete)* {5.4.1.2, 5.4.1.3, 6.4.2, 6.4.3}.

34 **Expanding and effectively managing the current network of protected areas, including terrestrial, freshwater and marine areas, is important for safeguarding biodiversity (*well established*), particularly in the context of climate change. Conservation outcomes also depend on adaptive governance, strong societal engagement, effective and equitable benefit-sharing mechanisms, sustained funding, and monitoring and enforcement of rules (*well established*) {6.2, 5.4.2}.** National Governments play a central role in supporting primary research, effective conservation and the sustainable use of multi-functional landscapes and seascapes. This entails planning ecologically representative networks of interconnected protected areas to cover key biodiversity areas and managing trade-offs between societal objectives that represent diverse worldviews and multiple values of nature *(established but incomplete)* {6.3.2.3, 6.3.3.3}. Safeguarding protected areas into the future also entails enhancing monitoring and enforcement systems, managing biodiversity-rich land and sea beyond protected areas, addressing property rights conflicts and protecting environmental legal frameworks against the pressure of powerful interest groups. In many areas, conservation depends on building capacity and enhancing stakeholder collaboration, involving non-profit groups as well as indigenous peoples and local communities to establish and manage marine protected areas and marine protected area networks, and proactively using instruments such as landscape-scale and seascape-scale participatory scenarios and spatial planning, including transboundary conservation planning *(well established)* {5.3.2.3, 6.3.2.3, 6.3.3.3}. Implementation beyond protected areas includes combating wildlife and timber trafficking through effective enforcement and ensuring the legality and sustainability of trade in wildlife. Such actions include prioritizing the prosecution of wildlife trafficking in criminal justice systems, using community-based social marketing to reduce demand and implementing strong measures to combat corruption at all levels *(established but incomplete)* {6.3.2.3}.

35 **Integrated landscape governance entails a mix of policies and instruments that together ensure nature conservation, ecological restoration and sustainable use, sustainable production (including of food, materials and energy), and sustainable forest management and infrastructure planning, and that address the major drivers of biodiversity loss and nature deterioration (*well established*) {6.3.2, 6.3.6}.** Policy mixes that are harmonized across sectors, levels of governance and jurisdictions can account for ecological and social differences across and beyond the landscape, build on existing forms of knowledge and governance and address trade-offs between tangible and non-tangible benefits in a transparent and equitable manner *(established but incomplete)*. Sustainable landscape management can be better achieved through multifunctional, multi-use, multi-stakeholder and community-based approaches *(well established)*, using a combination of measures and practices, including: (a) well-managed and connected protected areas and other effective area-based conservation measures; (b) reduced impact logging, forest certification, payment for ecosystem services, among other instruments, and reduced emissions from deforestation and forest degradation; (c) support for ecological restoration; (d) effective monitoring, including public access and participation as appropriate; (e) addressing illegal activities; (f) the effective implementation of multilateral environmental agreements and other relevant international agreements by

their parties; and (g) promoting sustainable, biodiversity-based food systems *(well established)* {6.3.2.1, 6.3.2.3, 6.3.2, 6.3.2.4}.

36 **Feeding the world in a sustainable manner, especially in the context of climate change and population growth, entails food systems that ensure adaptive capacity, minimize environmental impacts, eliminate hunger, and contribute to human health and animal welfare *(established but incomplete)* {5.3.2.1, 6.3.2.1}. Pathways to sustainable food systems entail land-use planning and sustainable management of both the supply/producer and the demand/consumer sides of food systems (*well established*) {5.3.2.1, 6.3.2.1, 6.4}.** Options for sustainable agricultural production are available and continue to be developed, with some having more impacts on biodiversity and ecosystem functions than others {6.3.2.1}. These options include integrated pest and nutrient management, organic agriculture, agroecological practices, soil and water conservation practices, conservation agriculture, agroforestry, silvopastoral systems, irrigation management, small or patch systems and practices to improve animal welfare. These practices could be enhanced through well-structured regulations, incentives and subsidies, the removal of distorting subsidies {2.3.5.2, 5.3.2.1, 5.4.2.1, 6.3.2}, and – at landscape scales – by integrated landscape planning and watershed management. Ensuring the adaptive capacity of food production entails the use of measures that conserve the diversity of genes, varieties, cultivars, breeds, landraces and species, which also contributes to diversified, healthy and culturally-relevant nutrition. Some incentives and regulations may contribute to positive changes at both the production and consumption ends of supply chains, such as the creation, improvement and implementation of voluntary standards, certification and supply-chain agreements (e.g., the Soy Moratorium) and the reduction of harmful subsidies. Regulatory mechanisms could also address the risks of co-option and lobbying, where commercial or sectoral interests may work to maintain high levels of demand, monopolies and continued use of pesticides and chemical inputs {5.3.2.1}. Non-regulatory alternatives are also important, and potentially include technical assistance – especially for small-holders – and appropriate economic incentive programs, for example, some payment for ecosystem services programmes and other non-monetary instruments {5.4.2.1}. Options that address and engage other actors in food systems (including the public sector, civil society, consumers and grassroots movements) include participatory on-farm research, the promotion of low-impact and healthy diets and the localization of food systems. Such options could help reduce food waste, overconsumption, and the demand for animal products that are produced unsustainably, which could have synergistic benefits for human health *(established but incomplete)* {5.3.2.1, 6.3.2.1}.

37 **Ensuring sustainable food production from the oceans while protecting biodiversity entails policy action to apply sustainable ecosystem approaches to fisheries management; spatial planning (including the implementation and expansion of marine protected areas); and more broadly, policy action to address drivers such as climate change and pollution (*well established*) {5.3.2.5, 6.3.3}.** Scenarios show that the pathways to sustainable fisheries entail conserving, restoring and sustainably using marine ecosystems, rebuilding overfished stocks (including through targeted limits on catches or fishing efforts and moratoria), reducing pollution (including plastics), managing destructive extractive activities, eliminating harmful subsidies and illegal, unreported and unregulated fishing, adapting fisheries management to climate change impacts and reducing the environmental impact of aquaculture *(well established)* {4, 5.3.2.5, 6.3.3.3.2}. Marine protected areas have demonstrated success in both biodiversity conservation and improved local quality of life when managed effectively and can be further expanded through larger or more interconnected protected areas or new protected areas in currently underrepresented regions and key biodiversity areas *(established but incomplete)* {5.3.2.5; 6.3.3.3.1}. Due to major pressures on coasts (including from development, land reclamation and water pollution), implementing marine conservation initiatives, such as integrated coastal planning, outside of protected areas is important for biodiversity conservation and sustainable use *(well established)* {6.3.3.3}. Other measures to expand multi-sectoral cooperation on coastal management include corporate social responsibility measures, standards for building and construction, and eco-labelling *(well established)* {6.3.3.3.2, 6.3.3.3.4}. Additional tools could include both non-market and market-based economic instruments for financing conservation, including for example payment for ecosystem services, biodiversity offset schemes, blue-carbon sequestration, cap-and-trade programmes, green bonds and trust funds and new legal instruments, such as the proposed international, legally binding instrument on the conservation and sustainable use of marine biological diversity in areas beyond national jurisdiction under the United Nations Convention on the Law of the Sea *(established but incomplete)* {6.3.3.2, 6.3.3.1.3, 5.4.2.1, 5.4.1.7}.

38 **Sustaining freshwater in the context of climate change, rising demand for water extraction and increased levels of pollution involves both cross-sectoral and sector-specific interventions that improve water-use efficiency, increase storage, reduce sources of pollution, improve water quality, minimize disruption and foster the restoration of natural habitats and flow regimes (*well established*) {6.3.4}.** Promising interventions include practising integrated water resource management and landscape planning across

scales; protecting wetland biodiversity areas; guiding and limiting the expansion of unsustainable agriculture and mining; slowing and reversing the de-vegetation of catchments; and mainstreaming practices that reduce erosion, sedimentation, and pollution run-off and minimize the negative impact of dams *(well established)* {6.3.4.6}. Sector-specific interventions include improved water-use efficiency techniques (including in agriculture, mining and energy), decentralized rainwater collection (for example, household-based), integrated management of surface and groundwater (e.g., "conjunctive use"), locally-developed water conservation techniques, and water pricing and incentive programmes (such as water accounts and payment for ecosystem services programmes) {6.3.4.2, 6.3.4.4}. With regard to watershed payment for ecosystem services programmes, their effectiveness and efficiency can be enhanced by acknowledging multiple values in their design, implementation and evaluation and setting up impact evaluation systems *(established but incomplete)* {6.3.4.4}. Investment in infrastructure, including in green infrastructure, is important, especially in developing countries, but it can be undertaken in a way that takes into account ecological functions and the careful blending of built and natural infrastructure {5.3.2.4, 6.3.4.5}.

39 **Meeting the Sustainable Development Goals in cities and making cities resilient to climate change entails solutions that are sensitive to social, economic and ecological contexts. Integrated city-specific and landscape-level planning, nature-based solutions and built infrastructure, and responsible production and consumption can all contribute to sustainable and equitable cities and make a significant contribution to the overall climate change adaptation and mitigation effort.** Urban planning approaches to promote sustainability include encouraging compact communities, designing nature-sensitive road networks and creating low-impact infrastructure and transportation systems (from an emissions and land-use perspective), including active, public and shared transport {5.3.2.6, 6.3.5}. However, given that most urban growth between now and 2030 will take place in the Global South, major sustainability challenges include creatively and inclusively addressing the lack of basic infrastructure (water, sanitation and mobility), the absence of spatial planning, and the limited governance capacity and financing mechanisms. Those challenges also offer opportunities for locally-developed innovation and experimentation, which will create new economic opportunities. A combination of bottom-up and city-level efforts through public, private, community and Government partnerships, can be effective in promoting low-cost and locally-adapted solutions to maintaining and restoring biodiversity and ecosystem functions and services. Nature-based options include combining grey and green infrastructure (such as wetland and watershed restoration and green roofs), enhancing green spaces through restoration and expansion, promoting urban gardens, maintaining and designing for ecological connectivity, and promoting accessibility for all (with benefits for human health). Additional solutions include disseminating new, low-cost technologies for decentralized wastewater treatment and energy production and creating incentives to reduce over-consumption {6.3.5}. Integrating cross-sectoral planning at the local, landscape and regional levels is important, as is involving diverse stakeholders *(well established)*. Particularly important at the regional scale are policies and programmes that promote sustainability-minded collective action {5.4.1.3}, protect watersheds beyond city jurisdictions and ensure the connectivity of ecosystems and habitats (e.g., through green belts). At the regional scale, cross-sectoral approaches to mitigating the impact of infrastructure and energy projects entail support for comprehensive environmental impact assessments and strategic environmental assessments of local and regional cumulative impacts {6.3.6.4, 6.3.6.6}.

40 **Decision makers have a range of options and tools for improving the sustainability of economic and financial systems *(well established)* {6.4}. Achieving a sustainable economy involves making fundamental reforms to economic and financial systems and tackling poverty and inequality as vital parts of sustainability (*well established*) {6.4}.** Governments could reform subsidies and taxes to support nature and its contributions to people, removing perverse incentives and instead promoting diverse instruments such as payments linked to social and environmental metrics, as appropriate *(established but incomplete)* {6.4.1}. At the international level, options for reacting to the challenges generated by the displacement of the impacts of unsustainable consumption and production on nature include both rethinking established instruments and developing new instruments to account for long-distance impacts. Trade agreements and derivatives markets could be reformed to promote equity and prevent the deterioration of nature, although there are uncertainties associated with implementation *(established but incomplete)* {6.4.4}. Alternative models and measures of economic welfare (such as inclusive wealth accounting, natural capital accounting and degrowth models) are increasingly considered as possible approaches to balancing economic growth and the conservation of nature and its contributions and to recognizing trade-offs, the pluralism of values, and long-term goals *(established but incomplete)* {6.4.5}. Structural changes to economies are also key to shifting action over long timescales. Such changes include technological and social innovation regimes and investment frameworks that internalize environmental impacts, such as the externalities of economic activities, including by addressing environmental impacts in socially just and appropriate ways *(well established)* {5.4.1.7}. Although such market-based policy instruments as payments for ecosystem services, voluntary certification and

biodiversity offsetting have increased in use, their effectiveness is mixed, and they are often contested; thus, they should be carefully designed and applied to avoid perverse effects in context *(established but incomplete)* {5.4.2.1, 6.3.2.2, 6.3.2.5, 6.3.6.3}. The widespread internalization of environmental impacts, including externalities associated with long-distance trade, is considered both an outcome and a component of national and global sustainable economies *(well established)* {5.4.1.6, 6.4}.

Table SPM 1 **Approaches for sustainability and possible actions and pathways for achieving them.**

The appropriateness and relevance of different approaches varies according to place, system, decision-making process and scale. The list of actions and pathways in the following table is illustrative rather than exhaustive and uses examples from the assessment report.

Approaches for sustainability	Possible actions and pathways to achieve transformative change Key actors: (IG=intergovernmental organizations, G=Governments, NGOs =non-governmental organizations, CG=citizen and community groups, IPLC = indigenous peoples and local communities, D=donor agencies, SO= science and educational organizations, P=private sector)
Enabling integrative governance to ensure policy coherence and effectiveness	• Implementing **cross-sectoral approaches** that consider linkages and interconnections between sectoral policies and actions (e.g., IG, G, D, IPLC) {6.2} {D1}. • **Mainstreaming biodiversity** within and across different sectors (e.g., agriculture, forestry, fisheries, mining, tourism) (e.g., IG, G, NGO, IPLC, CG, P, D) {6.2, 6.3.5.2} {D5}. • **Encouraging integrated planning and management for sustainability at the landscape and seascape levels** (e.g., IG, G, D) {6.3.2} {D5}. • **Incorporating environmental and socioeconomic impacts**, including externalities, into public and private decision-making (e.g., IG, G, P) {5.4.1.6} {B5}. • **Improving existing policy instruments** and using them **strategically and synergistically** in smart policy mixes (e.g., IG, G) {6.2, 6.3.2, 6.3.3.3.1, 6.3.4.6, 6.3.5.1, 6.3.6.1} {D4}.
Promoting inclusive governance approaches through stakeholder engagement and the inclusion of indigenous peoples and local communities to ensure equity and participation	• **Recognizing and enabling the expression of different value systems and diverse interests** while formulating and implementing policies and actions (e.g., IG, G, IPLCs, CG, NGO, SO, D) {6.2} {B5, D5}. • **Enabling the inclusion and participation** of indigenous peoples and local communities, and women and girls in environmental governance and **recognizing and respecting the knowledge, innovations, and practices, institutions and values** of indigenous peoples and local communities, in accordance with national legislation (e.g., G, IPLC, P) {6.2, 6.2.4.4} {D5}. • **Facilitating national recognition for land tenure, access and resource rights** in accordance with national legislation, and the application of **free, prior and informed consent and fair and equitable benefit-sharing arising from their use** (e.g., G, IPLC, P) {D5}. • Improving **collaboration and participation among** indigenous peoples and local communities, other relevant stakeholders, policymakers and scientists to generate novel ways of conceptualizing and achieving transformative change towards sustainability (e.g., G, IG, D, IPLC, CG, SO) {D5}.
Practicing informed governance for nature and nature's contributions to people	• **Improving the documentation of nature** (e.g., biodiversity inventory and other inventories) **and the assessment of the multiple values of nature, including the valuation of natural capital** by both private and public entities (e.g., SO, D, G, IG, P) {6.2} {D2}. • **Improving the monitoring and enforcement** of existing laws and policies through **better documentation and information-sharing** and **regular, informed and adaptive readjustments** to ensure transparent and enhanced results as appropriate (e.g., IG, G, IPLC, P) {D2}. • Advancing knowledge co-production and **including and recognizing different types of knowledge**, including indigenous and local knowledge and education, that enhances the legitimacy and effectiveness of environmental policies (e.g., SO, IG, G, D) {B6, D3}.
Promoting adaptive governance and management	• **Enabling locally tailored choices** about conservation, restoration, sustainable use and development connectivity that account for uncertainty in environmental conditions and scenarios of climate change (e.g., G, IPLC, CG, P) {D3}. • **Promoting public access to relevant information as appropriate** in decision-making and responsiveness to assessments by improving monitoring, including setting goals and objectives with multiple relevant stakeholders, who often have competing interests (e.g., IG, G). • **Promoting awareness-raising activities** around the principles of adaptive management, including through using short, medium and long-term goals that are regularly reassessed towards international targets (e.g., IG, G, SO, CG, D) {D4}. • Piloting and testing **well-designed policy innovations** that experiment with scales and models (e.g., G, D, SO, CG, IPLC) {D4}. • Increasing the **effectiveness of current and future international biodiversity targets and goals** (such as those of the post-2020 global biodiversity framework and of the Sustainable Development Goals), (e.g., IG, G, D) {6.2, 6.4}.

Approaches for sustainability	Possible actions and pathways to achieve transformative change Key actors: (IG=intergovernmental organizations, G=Governments, NGOs =non-governmental organizations, CG=citizen and community groups, IPLC = indigenous peoples and local communities, D=donor agencies, SO= science and educational organizations, P=private sector)
Managing sustainable and multifunctional landscapes and seascapes and some of the actions they may entail	
Producing and consuming food sustainably	• **Promoting sustainable agricultural practices**, including good agricultural practices, agroecology, among others, multifunctional landscape planning and cross-sectoral integrated management {6.3.2}. • **Sustainable use of genetic resources in agriculture,** including by conserving gene diversity, varieties, cultivars, breeds, landraces and species (e.g., SO, IPLC, CG) {6.3.2.1} {A6}. • **Promoting the use of biodiversity-friendly management practices** in crop and livestock production, forestry, fisheries and aquaculture, including, where relevant, the use of traditional management practices associated with indigenous peoples and local communities {6.3.2.1} {D6}. • **Promoting areas of natural or semi-natural habitat** within and around production systems, including those that are intensively managed, and restoring or reconnecting damaged or fragmented habitats where necessary {6.3.2.1} {D6}. • Improving **food market transparency** (e.g., traceability of biodiversity impacts, transparency in supply chains) through tools such as labelling and sustainability certification. • **Improving equity in food distribution and in the localization of food systems**, where appropriate and where beneficial to nature or nature's contributions to people (NCP). • **Reducing food waste from production to consumption.** • Promoting **sustainable and healthy diets** {6.3.2.1} {D6}.
Integrating multiple uses for sustainable forests	• Promoting **multifunctional, multi-use and multi-stakeholder approaches and improving community-based approaches** to forest governance and management to achieve sustainable forest management (e.g., IG, G, CG, IPLC, D, SO, P) {6.3.2.2} {A4}. • Supporting the **reforestation and ecological restoration** of degraded forest habitats with appropriate species, giving priority to native species (e.g., G, IPLC, CG, D, SO) {6.3.2.2} {A4}. • **Promoting and strengthening community-based management and governance, including customary institutions and management systems, and co-management regimes involving** indigenous peoples and local communities (e.g., IG, G, CG, IPLC, D, SO, P) {6.3.2.2} {D5}. • **Reducing the negative impact of** unsustainable **logging** by improving and implementing sustainable forest management, and **addressing illegal logging** (e.g., IG, G, NGO, P) {6.3.2.2} {D1}. • **Increasing efficiency in forest product use**, including incentives for adding value to forest products (such as sustainability labelling or public procurement policies), as well as promoting intensive production in well-managed forests so as to reduce pressures elsewhere (e.g., P, D, NGO) {6.3.2.2} {B1}.
Conserving, effectively managing and sustainably using terrestrial landscapes	• **Supporting, expanding and promoting effectively managed and ecologically representative networks** of well-connected protected areas and other multifunctional conservation areas, such as other effective area-based conservation measures (e.g., IG, G, IPLC, CG, D) {3.2.1, 6.3.2.3} {C1, D7}. • **Using extensive, proactive and participatory landscape-scale spatial planning** to prioritize land uses that balance and further safeguard nature and **to protect and manage key biodiversity areas** and other important sites for present and future biodiversity (e.g., IG, G, D) {B1, D7}. • Managing and restoring biodiversity beyond protected areas, (e.g., IG, G, CG, IPLC, P, NGO, D) {B1}. • **Developing robust and inclusive decision-making processes** that facilitate the positive contributions of indigenous peoples and local communities to sustainability by incorporating locally-attuned management systems and indigenous and local knowledge {B6, D5}. • **Improving and expanding the levels of financial support** for conservation and sustainable use through a variety of innovative options, including through partnerships with the private sector {6.3.2.5} {D5, D7, D10}. • **Prioritizing land-based adaptation and mitigation measures that do not have negative impacts on biodiversity** (e.g., reducing deforestation, restoring land and ecosystems, improving the management of agricultural systems such as soil carbon, and preventing the degradation of wetlands and peatlands) {D8}. • **Monitoring the effectiveness and impacts of protected areas** and other effective area-based conservation measures.
Promoting sustainable governance and management of seascapes, oceans and marine systems	• Promoting shared and **integrated ocean governance, including for biodiversity, beyond national jurisdictions** (e.g., IG, G, NGO, P, SO, D) {6.3.3.2} {D7}. • **Expanding, connecting and effectively managing marine protected area networks** (e.g., IG, G, IPLC, CG {5.3.2.3} {D7}, including protecting and managing priority marine key biodiversity areas and other important sites for present and future biodiversity, and **increasing protection and connectivity.** • **Promoting the conservation and/or restoration of marine ecosystems** through rebuilding overfished stocks; preventing, deterring and eliminating illegal, unreported and unregulated fishing; encouraging ecosystem-based fisheries management; and controlling pollution through the removal of derelict gear and through addressing plastics pollution (e.g., IG, G, P, IPLC, CG, SO, D) {B1, D7}. • **Promoting ecological restoration, remediation and the multifunctionality of coastal structures**, including through marine spatial planning (e.g., IG, G, NGO, P, CG, IPLC, SO, D) {6.3.3.3.1} {B1, D7}. • Integrating **ecological functionality concerns into the planning phase of coastal construction** (e.g., IG, G, NGO, P, CG, IPLC, SO, D) {6.3.3.3.1} {B1, D7}. • **Expanding multi-sectoral cooperation** by increasing and improving corporate social responsibility measures and regulation in building and construction standards, and eco-labelling and best practices (e.g., IG, G, NGO, P, CG, IPLC, SO, D) {6.3.3.3.1} {B1, D7}.

Table SPM 1 *(continued)*

Approaches for sustainability	Possible actions and pathways to achieve transformative change Key actors: (IG=intergovernmental organizations, G=Governments, NGOs =non-governmental organizations, CG=citizen and community groups, IPLC = indigenous peoples and local communities, D=donor agencies, SO= science and educational organizations, P=private sector)
Promoting sustainable governance and management of seascapes, oceans and marine systems	• **Encouraging effective fishery reform strategies** through incentives with positive impacts on biodiversity and through the removal of environmentally harmful subsidies (e.g., IG, G) {6.3.3.2} {D7}. • **Reducing the environmental impacts of aquaculture** by voluntary certification and by using best practices in fisheries and aquaculture production methods (e.g., G, IPLC, NGO, P) {6.3.3.3.2, 6.3.3.3.5} {B1, D7}. • **Reducing point and nonpoint source pollution**, including by managing marine microplastic and macroplastic pollution through effective waste management, incentives and innovation (e.g., G, P, NGO) {6.3.3.3.1} {B1, D7}. • **Increasing ocean conservation funding** (e.g., G, D, P) {6.3.3.1.3} {D7}.
Improving freshwater management, protection and connectivity	• **Integrating water resource management and landscape planning**, including through increased protection and connectivity of freshwater ecosystems, improving transboundary water cooperation and management, addressing the impacts of fragmentation caused by dams and diversions, and incorporating regional analyses of the water cycle (e.g., IG, G, IPLC, CG, NGO, D, SO, P) {6.3.4.6, 6.3.4.7} {B1}. • **Supporting inclusive water governance,** e.g., through developing and implementing invasive alien species management with relevant stakeholders (e.g., IG, G, IPLC, CG, NGO, D, SO, P) {6.3.4.3} {D4}. • **Supporting co-management regimes for collaborative water management** and **to foster equity** between water users (while maintaining a minimum ecological flow for the aquatic ecosystems), and engaging stakeholders and using transparency to minimize environmental, economic and social conflicts {D4}. • Mainstreaming practices that **reduce soil erosion, sedimentation and pollution run-off** (e.g., G, CG, P) {6.3.4.1}. • **Reducing the fragmentation of freshwater policies** by coordinating international, national and local regulatory frameworks (e.g., G, SO) {6.3.4.7, 6.3.4.2}. • **Increasing water storage** by facilitating groundwater recharge, wetlands protection and restoration, alternative storage techniques and restrictions on groundwater abstraction. (e.g., G, CG, IPLC, P, D) {6.3.4.2} {B1, B3}. • **Promoting investment in water projects** with clear sustainability criteria (e.g., G, P, D, SO) {6.3.4.5} {B1, B3}.
Building sustainable cities that address critical needs while conserving nature, restoring biodiversity, maintaining and enhancing ecosystem services	• Engaging **sustainable urban planning** (e.g., G, CG, IPLC, NGO, P) {6.3.5.1} {D9}. • **Encouraging densification for compact communities**, including through brownfield development and other strategies {6.3.5.3}. • **Including biodiversity protection, biodiversity offsetting, river basin protection, and ecological restoration in regional planning** {6.3.5.1}. • **Safeguarding urban key biodiversity areas** and ensuring that they do not become isolated through incompatible uses of surrounding land {6.3.5.2, SM 6.4.2}. • **Promoting biodiversity mainstreaming through stakeholder engagement and integrative planning** (e.g., G, NGO, CG, IPLC) {6.3.5.3}. • **Encouraging alternative business models and incentives for urban conservation** {6.3.2.1}. • **Promoting sustainable production and consumption** {6.3.6.4}. • **Promoting nature-based solutions** (e.g., G, NGO, SO, P) {6.3.5.2} {D8, D9}. • **Promoting, developing, safeguarding or retrofitting green and blue infrastructure** (for water management) while improving grey (hard) infrastructure to address biodiversity outcomes, {6.3.5.2}. • **Promoting ecosystem-based adaptation within communities** {3.7, 5.4.2.2}. • Maintaining and designing for **ecological connectivity within urban spaces**, particularly with native species {6.3.5.2, SM 6.4.1}. • **Increasing urban green spaces and improving access to them** {6.3.2}. • **Increasing access to urban services for low-income communities**, with priorities for sustainable water management, integrated sustainable solid waste management and sewage systems, and safe and secure shelter and transport (e.g., G, NGO) {6.3.5.4} {D9}.
Promoting sustainable energy and infrastructure projects and production	• Developing **sustainable strategies, voluntary standards and guidelines** for sustainable renewable energy and bioenergy projects (e.g., G, SO, P) {6.3.6} {D8}. • Strengthening and promoting **biodiversity-inclusive environmental impact assessments**, laws and guidelines {6.3.6.2} {B1}. • **Mitigating environmental and social impacts** where possible and **promoting innovative financing and restoration** when necessary (e.g., G, P, NGO, D) {6.3.6.3} {B1}, including by redesigning **incentive programmes and policies** to promote bioenergy systems that optimize trade-offs between biodiversity loss and benefits (e.g., through life cycle analysis) {D8}. • **Supporting community-based management and decentralized** sustainable energy production (e.g., G, CG, IPLC, D) {6.3.6.4, 6.3.6.5} {D9}. • **Reducing energy demands** so as to reduce the demand for biodiversity-impacting infrastructure (e.g., through energy efficiency, new clean energy and reducing unsustainable consumption) (e.g., G, P) {B1}.

Approaches for sustainability	Possible actions and pathways to achieve transformative change Key actors: (IG=intergovernmental organizations, G=Governments, NGOs =non-governmental organizations, CG=citizen and community groups, IPLC = indigenous peoples and local communities, D=donor agencies, SO= science and educational organizations, P=private sector)
Improving the sustainability of economic and financial systems	• **Developing and promoting incentive structures** to protect biodiversity (e.g., removing harmful incentives) (e.g., IG, G) {6.4} {D10}. • Promoting **sustainable production and consumption**, such as through: sustainable sourcing, resource efficiency and reduced production **impacts**, circular and other economic models, corporate social responsibility, life-cycle assessments that include biodiversity, trade agreements and public procurement policies (e.g., G, CA, NGO, SO) {6.4.3, 6.3.2.1} {D10}. • **Exploring alternative methods of economic accounting** such as natural capital accounting and Material and Energy Flow Accounting, among others (e.g., IG, G, SO) {6.4.5} {D10}. • **Encouraging policies that combine poverty reduction** with measures to increase the provision of nature's contributions and the conservation and sustainable use of nature (e.g., IG, G, D) {3.2.1} {C2}. • **Improving market-based instruments**, such as payment for ecosystem services, voluntary certification and biodiversity offsetting, to address challenges such as equity and effectiveness (e.g., G, P, NGO, IPLC, CG, SO) {B1}. • **Reducing consumption** (e.g., encouraging consumer information to reduce overconsumption and waste, using public policies and regulations and internalizing environmental impacts) (e.g., G, P, NGO) {B4, C2}. • **Creating and improving supply-chain models** that reduce the impact on nature {D3}.

APPENDICES

APPENDIX 1
Conceptual framework and definitions

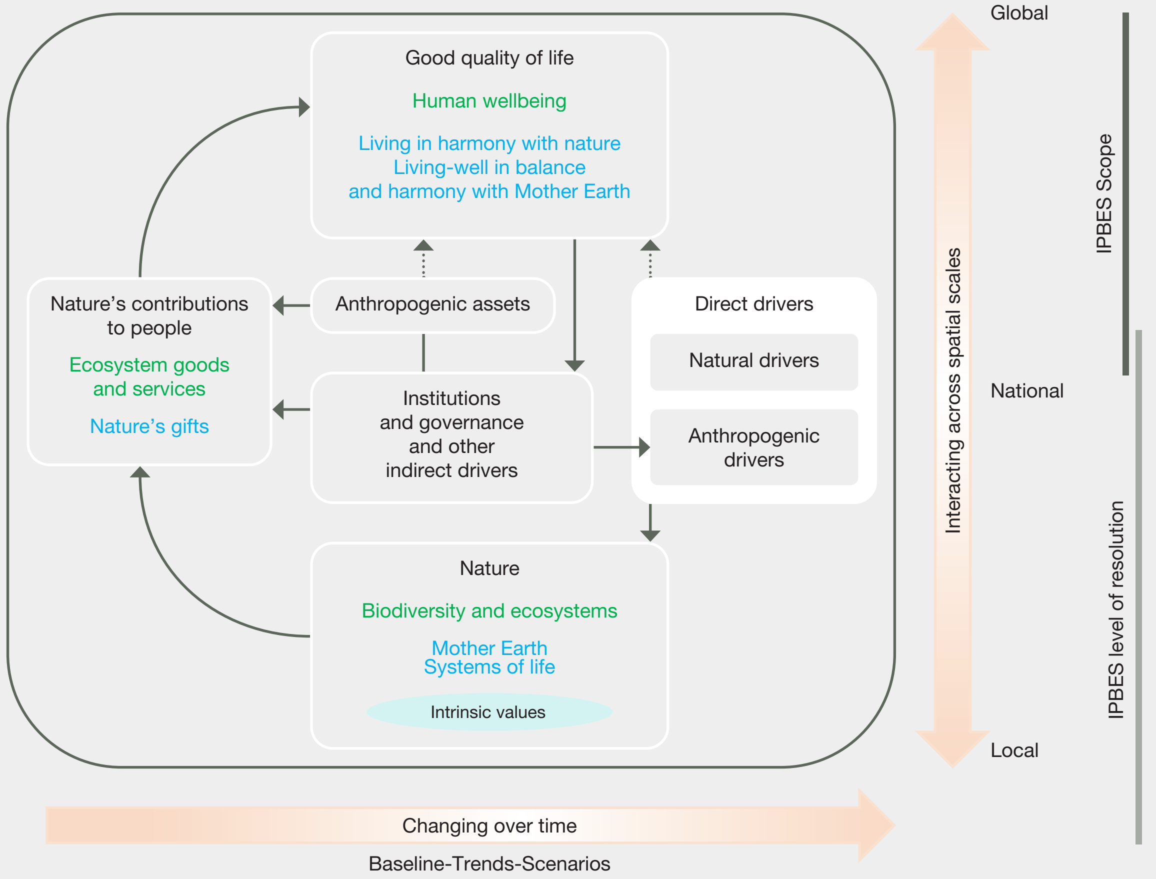

Figure SPM A 1 **The IPBES conceptual framework. Source: Díaz *et al.* (2015).**

Figure SPM A1. The IPBES Conceptual Framework is a highly simplified model of the complex interactions between the natural world and human societies. The model identifies the main elements (boxes within the main panel outlined in grey), together with their interactions (arrows in the main panel), that are most relevant to the Platform's goal. "Nature", "nature's contributions to people" and "good quality of life" (indicated as black headlines and defined in each corresponding box) are inclusive categories that were identified as meaningful and relevant to all stakeholders involved in IPBES during a participatory process, including various disciplines of the natural and social sciences and the humanities, and other knowledge systems, such as those of indigenous peoples and local communities. Text in green denotes scientific concepts, and text in blue denotes concepts originating in other knowledge systems. The solid arrows in the main panel denote influence between elements, and dotted arrows denote links that are acknowledged as important, but that are not the main focus of the Platform. The thick coloured arrows below and to the right of the central panel indicate the scales of time and space, respectively. This conceptual framework was accepted by the Plenary in decision IPBES-2/4, and the Plenary took note of an update presented in IPBES/5/INF/24 and in decision IPBES-5/1. Further details and examples of the concepts defined in the box can be found in the glossary and in Chapter 1.

Nature, in the context of the Platform, refers to the natural world, with an emphasis on biodiversity. Within the context of science, it includes categories such as biodiversity, ecosystems, ecosystem functioning, evolution, the biosphere, humankind's shared evolutionary heritage, and biocultural diversity. Within the context of other knowledge systems, it includes categories such as Mother Earth and systems of life. Other components of nature, such as deep aquifers, mineral and fossil reserves, and wind, solar, geothermal and wave power, are not the focus of the Platform. Nature contributes to societies through the provision of contributions to people.

Anthropogenic assets refers to built-up infrastructure, health facilities, knowledge (including indigenous and local knowledge systems and technical or scientific knowledge, as well as formal and non-formal education), technology (both physical objects and procedures), and financial assets, among others. Anthropogenic assets have been highlighted to emphasize that a good life is achieved by a co-production of benefits between nature and societies.

Nature's contributions to people refers to all the contributions that humanity obtains from nature. Ecosystem goods and services, considered separately or in bundles, are included in this category. Within other knowledge systems, nature's gifts and similar concepts refer to the benefits of nature from which people derive good quality of life. Aspects of nature that can be negative to people (detriments), such as pests, pathogens or predators, are also included in this broad category.

Nature's regulating contributions to people refers to functional and structural aspects of organisms and ecosystems that modify the environmental conditions experienced by people, and/or sustain and/or regulate the generation of material and non-material contributions. For example, these contributions include water purification, climate regulation and the regulation of soil erosion.

Nature's material contributions to people refers to substances, objects or other material elements from nature that sustain people's physical existence and the infrastructure (i.e. the basic physical and organizational structures and facilities, such as buildings, roads, power supplies) needed for the operation of a society or enterprise. They are typically physically consumed in the process of being experienced, such as when plants or animals are transformed into food, energy, or materials for shelter or ornamental purposes.

Nature's non-material contributions to people refers to nature's contribution to people's subjective or psychological quality of life, individually and collectively. The entities that provide these intangible contributions can be physically consumed in the process (e.g., animals in recreational or ritual fishing or hunting) or not (e.g., individual trees or ecosystems as sources of inspiration).

Drivers of change refers to all those external factors that affect nature, anthropogenic assets, nature's contributions to people and good quality of life. They include institutions and governance systems and other indirect drivers, and direct drivers (both natural and anthropogenic).

Institutions and governance systems and other indirect drivers are the ways in which societies organize themselves and the resulting influences on other components. They are the underlying causes of environmental change that are exogenous to the ecosystem in question. Because of their central role, influencing all aspects of human relationships with nature, they are key levers for decision-making. “Institutions” encompasses all formal and informal interactions among stakeholders and the social structures that determine how decisions are taken and implemented, how power is exercised, and how responsibilities are distributed. To varying degrees, institutions determine the access to and control, allocation and distribution of the components of nature and of anthropogenic assets and their contributions to people. Examples of institutions are systems of property and access rights to land (e.g., public, common-pool or private), legislative arrangements, treaties, informal social norms and rules, including those emerging from indigenous and local knowledge systems, and international regimes such as agreements against stratospheric ozone depletion or for the protection of endangered species of wild fauna and flora. Economic policies, including macroeconomic, fiscal, monetary or agricultural policies, play a significant role in influencing people's decisions and behaviour and the way in which they relate to nature in the pursuit of benefits. However, many of the drivers of human behaviour and preferences, which reflect different perspectives on a good quality of life, work largely outside the market system.

Direct drivers, both natural and anthropogenic, affect nature directly. “Natural drivers” are those that are not the result of human activities and are beyond human control. These include earthquakes, volcanic eruptions and tsunamis, extreme weather or ocean-related events such as prolonged drought or cold periods, tropical cyclones and floods, the El Niño/La Niña Southern Oscillation and extreme tidal events. The direct anthropogenic drivers are those that are the result of human decisions, namely, of institutions and governance systems and other indirect drivers. Anthropogenic drivers include habitat conversion, e.g., degradation of land and aquatic habitats, deforestation and afforestation, exploitation of wild populations, climate change, pollution of soil, water and air and species introductions. Some of these drivers, such as pollution, can have negative impacts on nature; others, as in the case of habitat restoration, or the introduction of a natural enemy to combat invasive species, can have positive effects.

Good quality of life is the achievement of a fulfilled human life, a notion which varies strongly across different societies and groups within societies. It is a context-dependent state of individuals and human groups, comprising access to food, water, energy and livelihood security, and also health, good social relationships and equity, security, cultural identity, and freedom of choice and action. From virtually all standpoints, a good quality of life is multidimensional, having material as well as immaterial and spiritual components. What a good quality of life entails, however, is highly dependent on place, time and culture, with different societies espousing different views of their relationships with nature and placing different levels of importance on collective versus individual rights, the material versus the spiritual domain, intrinsic versus instrumental values, and the present time versus the past or the future. The concept of human well-being used in many western societies and its variants, together with those of living in harmony with nature and living well in balance and harmony with Mother Earth, are examples of different perspectives on a good quality of life.

APPENDIX 2
Communication of the degree of confidence

Figure SPM A 2 **The four-box model for the qualitative communication of confidence.**

Confidence increases towards the top-right corner as suggested by the increasing strength of shading. Source: IPBES (2016).[16]

In this assessment, the degree of confidence in each main finding is based on the quantity and quality of evidence and the level of agreement regarding that evidence **(Figure SPM.A2)**. The evidence includes data, theory, models and expert judgement. Further details of the approach are documented in the note by the secretariat on the information on work related to the guide on the production of assessments (IPBES/6/INF/17).

- **Well established:** there is a comprehensive meta-analysis or other synthesis or multiple independent studies that agree.
- **Established but incomplete:** there is general agreement, although only a limited number of studies exist; there is no comprehensive synthesis, and/or the studies that exist address the question imprecisely.
- **Unresolved:** multiple independent studies exist but their conclusions do not agree.
- **Inconclusive:** there is limited evidence and a recognition of major knowledge gaps.

16. IPBES, Summary for policymakers of the assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production. S.G. Potts, V. L. Imperatriz-Fonseca, H. T. Ngo, J. C. Biesmeijer, T. D. Breeze, L. V. Dicks, L. A. Garibaldi, R. Hill, J. Settele, A. J. Vanbergen, M. A. Aizen, S. A. Cunningham, C. Eardley, B. M. Freitas, N. Gallai, P. G. Kevan, A. Kovács-Hostyánszki, P. K. Kwapong, J. Li, X. Li, D. J. Martins, G. Nates-Parra, J. S. Pettis, R. Rader, and B. F. Viana (eds.)., secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany, 2016. Available at http://doi.org/10.5281/zenodo.2616458.

APPENDIX 3
Knowledge gaps

In the course of conducting this assessment key information needs were identified. See draft table Appendix IV.

- Data, inventories and monitoring on nature and the drivers of change
- Gaps on biomes and units of analysis
- Taxonomic gaps
- NCP-related gaps
- Links between nature, nature's contributions to people and drivers with respect to targets and goals
- Integrated scenarios and modelling studies
- Potential policy approaches
- Indigenous peoples and local communities

APPENDIX 4
Draft table of knowledge gaps

Disclaimer: This table of knowledge gaps was prepared by the experts of the Global Assessment and presented to and considered by a working group established by the Plenary at its seventh session. The Plenary did not approve this table as part of the summary for policymakers. It is therefore included in draft form, which does not imply working group or Plenary approval.

Sector	Knowledge gaps (in data, indicators, inventories, scenarios)[17]
Data, inventories and monitoring on nature and the drivers of change	• Data on ecosystem processes (including rates of change) that underpin nature's contributions to people and ecosystem health • Data from monitoring of ecosystem condition (generally less well represented than ecosystem extent) • Data on changing interactions among organisms and taxa • Impacts of increasing CO_2 upon the total Net Primary Production of marine systems, and consequences for ecosystem function and nature's contributions to people • Syntheses of how human impacts affect organismal traits and global patterns and trends in genetic composition • Data on extinction risks and population trends, especially for insects, parasites and fungal and microbial species • Indicators on the global extent and consequences of biotic homogenization, including genetic homogenization • Global spatial datasets on key threats, e.g., data on patterns in the intensity of unsustainable exploitation of species and ecosystems • More comprehensive understanding of how human-caused changes to any Essential Biodiversity Variable class (e.g., ecosystem structure) have impacts on others (e.g., community composition) and on nature's contributions to people • Data gaps in key inventories: World Database on Protected Areas, the World Database of Key Biodiversity Areas™, red lists of threatened species and ecosystems, and the Global Biodiversity Information Facility • Monitoring of many listed species in the Convention on International Trade in Endangered Species of Wild Fauna and Flora. • Monitoring of the long-term effects of dumped waste, especially radioactive material and plastics • Data on the impacts of war and conflict on nature and nature's contributions to people
Gaps on biomes and units of analysis	• Inventories on under-studied ecosystems: freshwater, Arctic, marine/ocean, seabed, and wetlands • Inventories in soil, benthic and freshwater environments, and the implications for ecosystem functions
Taxonomic gaps	• Basic data on many taxa (86 per cent of existing species on Earth and 91 per cent of species in the ocean still await description) • Extinction risks and population trends for the following taxonomic groups: insects, fungal species, microbial species (microorganisms) and parasites • Data on the genetic diversity and conservation status of breeds of farmed and domestic plants and animals
NCP-related gaps	• Data on the status of species and nature's contributions to people linked to specific ecosystem functions • Systematic indicators to report the status and trends for categories of nature's contributions to people • Data on the impacts and extent of nature's contributions to people on quality of life, by major user group (also lacking an agreed typology on major user groups) • Data on the interrelationships between gender equality, nature and nature's contributions to people • Data and information on NCP 10: regulation of detrimental organisms and biological processes (populations of vectors and vector-borne diseases) and overlaps with vulnerable human populations and ecosystem interactions • Data and information on NCP 9: the role of nature and nature's contributions to people in mitigating or reducing vulnerability to disasters

17. This list of knowledge gaps in the IPBES Global Assessment of Biodiversity and Ecosystem Services is not exhaustive.

Sector	Knowledge gaps (in data, indicators, inventories, scenarios)[17]
Links between nature, nature's contributions to people and drivers with respect to targets and goals	• Understanding on how nature contributes to achieving targets (the positive and negative relationships between nature and targets/goals like the Sustainable Development Goals) • Disaggregated data on the impacts that nature has on good quality of life, particularly across regions, societies, governance systems, and ecosystems • Need for indicators for some Sustainable Development Goals and Aichi Biodiversity Targets (e.g., Aichi Biodiversity Target 15 on ecosystem resilience and contribution of biodiversity to carbon stocks and Target 18 on integration of traditional knowledge and effective participation of indigenous peoples and local communities) • Better quantitative data to assess the Sustainable Development Goals and Aichi Targets where qualitative indicators havebeen dominant (9 out of 44 targets under the Sustainable Development Goals reviewed) • Data on the benefits to human mental health from exposure to natural environments • Indicators that reflect the heterogeneity of indigenous peoples and local communities
Integrated scenarios and modelling studies	• Regional and global socioeconomic scenarios explicitly considering the knowledge, views and perspectives of indigenous peoples and local communities • Regional and global ssocioeconomic scenarios developed for, by and in collaboration with indigenous peoples and local communities and their associated institutions • Quantitative data showing how nature, its contributions to people, and good quality of life interact and change in time along different pathways • Scenarios of the future of biodiversity which quantify the possible co-benefits related to nature's contributions to people • Scenarios about nonmaterial benefits to people compared to material benefits and regulating benefits • Integrated scenarios for areas projected to experience significant impacts and possible regime shifts (e.g., Arctic, semi-arid regions, and small islands) • Knowledge about the interaction, feedback and spill-overs among regions within future global scenarios • Assessment of nature's contributions to people across scenario archetypes with robust knowledge and quantitative estimates
Potential policy approaches	• Data to analyse the effectiveness of many policy options and interventions, including: a) Data on the comparative effectiveness of different area-based conservation mechanisms (e.g., protected areas, other effective area-based conservation measures) in conserving nature and nature's contributions to people and contributing to good quality of life b) Indicators of the effectiveness of different restoration methodologies and to assess restoration progress over time (including values) c) Data on the comparative effectiveness of different processes of access and benefit sharing to ensure fairness and equity d) Better data on the global extent and forms of wildlife trafficking and its impacts on nature and nature's contributions to people e) Data on the comparative effectiveness of different models for reconciling bioenergy and biodiversity conservation f) Data on the effectiveness of different schemes and models for payment for ecosystem services (PES), particularly the trade-offs that arise between policy goals, the integration of multiple values in PES, data on the profiles of PES participants and long-term monitoring of relational and behavioural implications of participation g) Data on the comparative effectiveness of different models of marine governance relating to conservation • Data on the extent of the participation of indigenous peoples and local communities in environmental governance • Indicators on the impacts of environmentally harmful subsidies and trends and effectiveness of their removal at the global level • Data on areas of uncertainty in applying the precautionary principle • Data on the monitoring of policy effectiveness to adapt and adjust policies and to share lessons • Data on the impacts of resource mobilization, using robust program evaluation methods (e.g., examples of successful use of funding including impacts of donor funding for conservation and impacts of specific biodiversity financing projects) • Data on the impacts of climate change on marine and coastal governance regimes • Data on the impacts of mainstreaming of biodiversity across sectors • Better data to develop biodiversity and environmental quality standards
Indigenous Peoples and Local Communities	• Agreed-upon methods to enable systematic processes of knowledge generation, collection and synthesis regarding indigenous and local knowledge (for assessments and elsewhere) and participation of indigenous peoples and local communities in this process • Syntheses of indigenous and local knowledge about the status and trends in nature • Data to assess how progress in achieving goals and targets affects indigenous peoples and local communities, either in positive or in negative ways • Trends in relation to the socioeconomic status of indigenous peoples and local communities (e.g., noting the lack of data differentiation in aggregate statistics)


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Chapter **1.**

ASSESSING A PLANET IN TRANSFORMATION: RATIONALE AND APPROACH OF THE IPBES GLOBAL ASSESSMENT ON BIODIVERSITY AND ECOSYSTEM SERVICES

IPBES GLOBAL ASSESSMENT REPORT ON BIODIVERSITY AND ECOSYSTEM SERVICES
CHAPTER 1. ASSESSING A PLANET IN TRANSFORMATION: RATIONALE AND APPROACH OF THE IPBES GLOBAL ASSESSMENT ON BIODIVERSITY AND ECOSYSTEM SERVICES

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CHAPTER 1

ASSESSING A PLANET IN TRANSFORMATION: RATIONALE AND APPROACH OF THE IPBES GLOBAL ASSESSMENT ON BIODIVERSITY AND ECOSYSTEM SERVICES

1.1 SETTING THE STAGE

1.1.1 The scope of the IPBES Global Assessment on Biodiversity and Ecosystem Services

The challenges of mitigating and adapting to climate change, achieving inclusive food, water, energy and health security, addressing urban vulnerabilities, and the unequal burdens of nature deterioration, are not only predicaments on their own right. Because they interact, often exacerbating each other, they create new risks and uncertainties for people and nature. It is now evident that the rapid deterioration of nature, including that of the global environmental commons on land, ocean, atmosphere and biosphere, upon which humanity as a whole depends, are interconnected and their cascading effects compromise societal goals and aspirations from local to global levels. Growing efforts to respond to these challenges and awareness of our dependence on nature have opened new opportunities for action and collaboration towards fairer and more sustainable futures.

The global assessment on biodiversity and ecosystem services (GA) has been designed to be a comprehensive and ambitious intergovernmental integrated assessment of recent anthropogenic transformations of Earth's living systems, the roots of such transformations, and their implications to society. In the chapters that follow, our mandate is to critically assess the state of knowledge on recent past (from the 1970s), present and possible future trends in multi-scale interactions between people and nature, taking into consideration different worldviews and knowledge systems, including those representing mainstream natural and social sciences and the humanities, and indigenous and local knowledge systems. In doing so, the GA also assesses where the world stands in relation to several international agreements related to biodiversity and sustainable development.

This challenging task, mandated by the 123 member-countries (2016) of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), reflects the evolution of international collective thinking and action and fulfils several goals. It reflects an increasingly shared understanding that the human imprint at a global scale has made our social worlds intertwined with the larger Earth biophysical systems and fabric of life. It represents a shared understanding that internationally agreed goals for sustainable development, biodiversity conservation and climate change are interdependent in their pathways to success. As such, the GA examines our past trajectories, our actions today and the opportunities going forward as part of an interdependent global social-ecological system, with its own emergent properties, undergoing fast changes and modes of functioning. Earth history has become intertwined with human history. At the same time, it is increasingly obvious that the planet is highly heterogeneous and yet highly interconnected, physically and virtually, socially as well as ecologically. Global connectivity and unity do not mean uniformity; shared goals do not mean a single pathway.

To accomplish its goals, the GA examines the current status, past and future trends in nature, development pathways across world regions, interactions between and among direct and indirect drivers of change within and across them, human values towards the environment and response options regarding nature both on land and under water and nature's contributions to people's quality of life in landscapes and seascapes under different degrees of human intervention. A hallmark component of the GA is its systematic cross-chapter and cross-scale attention to indigenous and local knowledge (ILK) and issues concerning Indigenous Peoples and Local Communities (IPLCs), scaling-up and providing syntheses, where appropriate, at regional and global levels.

The timeframe examined in the assessment includes going back as far as 50 years (or longer) so that current status and trends up to 2020 can be seen in context. Scenarios and plausible future projections are examined with a focus on various periods between 2020 and 2050, covering key target dates related to the Strategic Plan for Biodiversity 2011–2020 and the 2030 Agenda for Sustainable Development and its Sustainable Development Goals, as well as overall trends across the next 50 years. An important aspect of the GA is to examine the synergies and trade-offs associated with meeting multiple goals and the interactions among the social, economic and environmental dimensions underlying possible pathways to the future. Another major goal is to examine policy options and solutions in an integrated way, so that specific goals such as feeding the world, sustaining the world's fisheries, mitigating climate change, or providing water security to all do not undermine, but rather leverage on each other.

This task is structured according to five overarching questions defined in the global assessment scoping report[1]:

(a) What is the status of and trends in nature, nature's contributions to people and indirect and direct drivers of change?

(b) How do nature and its contributions to people influence the implementation of the Sustainable Development Goals? What is the evidence base that can be used for assessing progress towards the achievement of the Aichi Biodiversity Targets?

(c) What are the plausible futures for nature, nature's contributions to people and their impacts on quality of life between now and 2050?

(d) What pathways and policy intervention scenarios relating to nature, nature's contributions to people and their impacts on quality of life can lead to sustainable futures?

(e) What are the opportunities and challenges, as well as options available to decision makers, at all levels relating to nature, its contributions to people and their impacts on quality of life?

The assessment of evidence regarding these five questions is guided by the IPBES conceptual framework and a series of analytical frameworks described in this chapter. The GA builds upon a series of preceding IPBES assessments, which include an assessment on pollination (IPBES, 2016a), a methodological assessment of scenarios and models (IPBES, 2016b), four regional assessments (IPBES, 2018b, 2018c, 2018d, 2018e) and the land degradation and restoration assessment (IPBES, 2018a). Besides its specific mandate, the GA addresses issues of a global nature not fully covered in those assessments, paying particular attention to inter-regional interactions and their emergent global outcomes.

1. Annex I to decision IPBES-4/1, 2016.

The goal of the GA is to provide relevant, credible, legitimate, authoritative, evidence-based, and comprehensive analyses of the state of knowledge these questions, informing a range of stakeholders in the public and private sectors and civil society. These include governments, multilateral organizations, the private sector and civil society, including IPLCs and non-governmental organizations. The assessment is organized to contribute directly – although by no means exclusively – to the evaluation of the UN Convention on Biological Diversity's (CBD) Strategic Plan for Biodiversity 2011–2020 (including the Aichi Biodiversity Targets) and its 2050 Vision for Biodiversity. It informs the upcoming fifth edition of the Global Biodiversity Outlook (GBO) of the Convention on Biological Diversity, which in 2020 will report on the implementation and the achievements of the Strategic Plan for Biodiversity 2011–2020 and consider ways forward.

The GA also contributes to the evaluation of progress towards achieving the 2030 United Nations Sustainable Development Goals (SDGs), particularly goals related to the natural environment and biodiversity. The GA also assesses progress towards ten other environment-related international agreements (see description of chapter 3 below), and intends to contribute, among others, to national and regional assessments and strategies. Evaluations of these agreements and the guiding questions presented above consider current and projected climate change scenarios and proposed pathways to achieve the goals of the Paris Agreement on Climate.

A road map to the chapters of the Global Assessment

As other IPBES assessments, the GA is a critical evaluation of the state of knowledge carried out under the principles of relevancy, legitimacy and credibility. The GA has not undertaken new primary research, but analysed, synthetized and critically evaluated available information and data previously published or otherwise made available in the public domain in a traceable way. The questions presented above provide a framework for evaluating and integrating evidence from local to global levels, spanning past and future.

The GA chapters are organized to accomplish a two-fold goal: to provide in-depth knowledge on specific issues and domains (using diverse expertise and perspectives, evidence and indicators), and to build upon each other in the spirit of cumulative understanding of cross-cutting issues. For instance, chapter 1 provides a common framework, language, and set of analytical tools that supports all chapters; the three subchapters of chapter 2 provide detailed evidence on status and trends to date, providing support for chapter 3 to examine progress towards the 2011–2020 Aichi Biodiversity Targets, the 2030 SDGs, and other environmental agreements; both chapters provide the

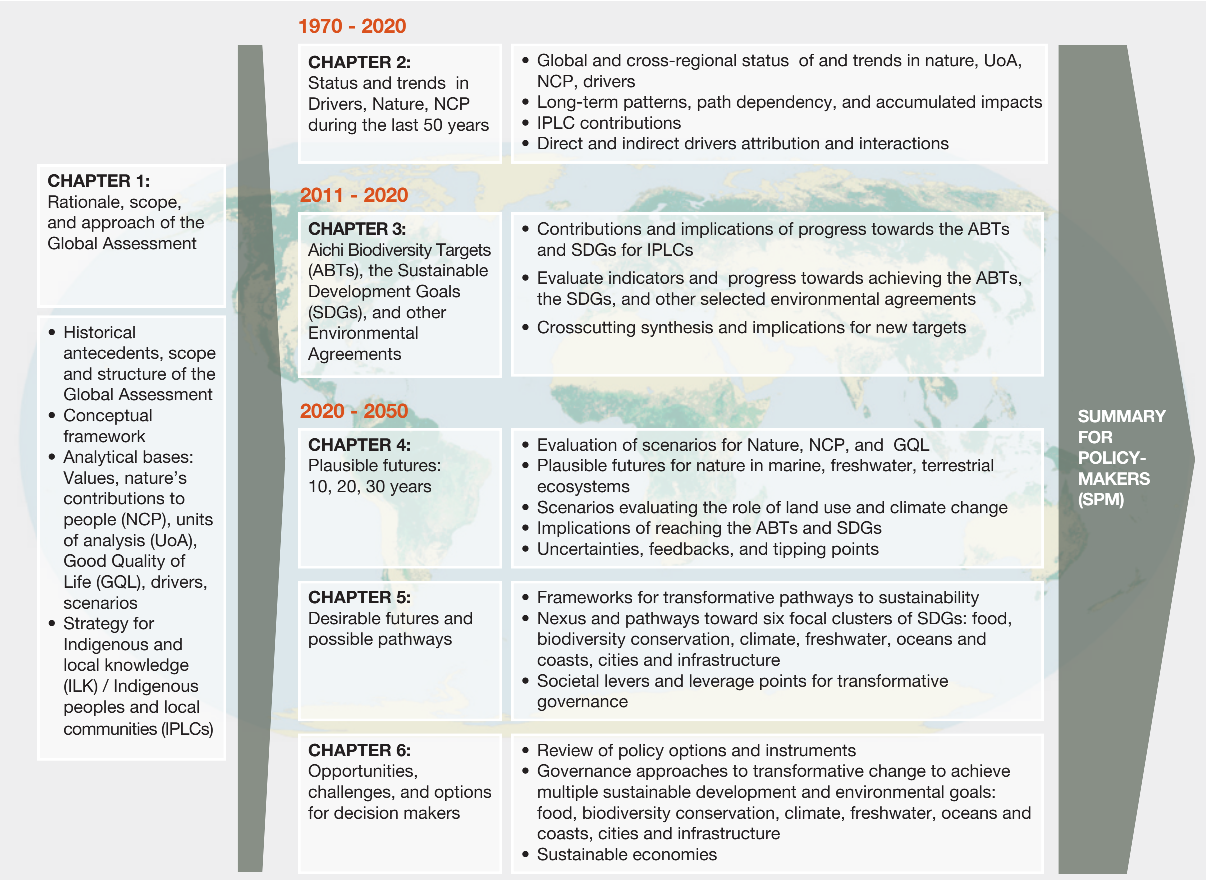

Figure 1 1 **A schematic representation of the chapters of the Global Assessment (GA).**

elements for the analyses presented in chapters 4, 5, and 6. Together, the chapters develop a storyline starting with the social-ecological transformation of the Earth particularly during the past 50 years, examining current progress in confronting the challenges posed by such transformation, evaluating the outlook of the near and more distant futures, and reflecting the potential pathways and policy options to fairer, more resilient and sustainable futures.

1.1.2 The chapters: Unfolding the story of global changes and what to do about them

What follows in chapter 1 starts with contextualizing the GA within a longer lineage of efforts to understand global changes and possible pathways to sustainability. It then provides a detailed discussion of the IPBES conceptual framework supporting the assessment, explaining its main elements and interactions. The nature's contribution to people approach is presented as a product of evolving ideas since the popularization of ecosystem services concepts and approaches. Next, this approach and its derived analytical categories are explained, followed by a presentation of other key analytical tools used in the assessment, including values towards nature, institutions and governance, good quality of life, direct and indirect drivers, and units of analysis. This is followed by a detailed discussion of the operational strategy to integrate and scale-up from local to global levels, and systematically across chapters, issues concerning IPLCs and evidences from ILK. Finally, other supporting tools used in the assessment are presented, including scenarios, indicators, literature review, units of analysis, typology of drivers and confidence framework.

Chapter 2 addresses the question *What are the current status as well as the trends for nature, nature's contributions to people, and their indirect and direct drivers?* Given its enormous scope, the chapter is broken into three subchapters.

The first of chapter 2 subchapters (2.1), *Drivers*, examines the status and trends for drivers that affect nature directly (arrow 3 of the IPBES conceptual framework, **Figure 1.2**), and indirectly (arrow 2), including across regions. It emphasizes anthropogenic drivers and examines the development trajectories for different groups of countries, during the past 30–50 years, given their economic and environmental interactions. It considers how values and their expressions in decisions affect demands for contributions from nature, given related socioeconomic processes including evolving governance institutions (arrow 1), and how these indirect drivers in turn affect direct drivers acting directly on nature and their aggregated consequences (arrow 2).

The second subchapter (2.2), *Nature*, unpacks the nature box of the IPBES conceptual framework. After setting the stage by discussing different perspectives and worldviews about nature, it outlines nature's many different aspects, such as biodiversity and ecosystem structure and function, and the contributions of IPLCs to wild and domesticated biodiversity and to their management and conservation. The subchapter assesses status and trends of nature, using both a wide array of globally relevant indicators from marine, terrestrial and freshwater ecosystems and the first global synthesis of IPLCs indicators of local-scale change. It assesses the relative impacts of the main direct drivers on nature globally (arrow 3) as well as reports on each unit of analysis. This subchapter also describes how the many facets of nature underpin its contributions to people (arrow 4).

The third of Chapter 2 subchapters (2.3), *Nature's Contributions to People (NCP)*, describes status and trends of nature's contributions, both positive and negative, to human quality of life. This section presents a summary of status and trends globally, and highlights differences across ecosystem types and regions, for 18 NCP that span regulating, material, and non-material contributions. This section discusses the co-production of NCP by people and nature, as well as the impact that NCP has on different user groups. This section also examines multiple dimensions of value that describe impacts on human quality of life.

Chapter 3 addresses the questions of *How much progress has been made towards the Aichi Biodiversity Targets and the objectives of other biodiversity-related agreements, and how do nature and its contributions to people contribute to the implementation of the Sustainable Development Goals?* Building upon findings from chapter 2 and additional evidence from analyses of indicators and literature reviews, the chapter assesses progress towards meeting major international objectives related to biodiversity and sustainable development, with special attention given to the Aichi Biodiversity Targets and to relevant (i.e., directly biodiversity-related) Sustainable Development Goals. The chapter also examines the objectives of other biodiversity-related agreements: Convention on Migratory Species (CMS), Convention on International Trade in Endangered Species (CITES), Ramsar Convention on Wetlands (Ramsar), Convention to Combat Desertification (UNCCD), World Heritage Convention (WHC), International Plant Protection Convention (IPPC), Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), the Arctic Council's Conservation of Arctic Flora and Fauna (CAFF), the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), and the Convention on the Law of the Sea (UNCLOS). The chapter assesses the contributions of Indigenous Peoples and Local Communities (IPLCs) to achieve biodiversity goals and targets, and how progress towards them (or lack of it) affects IPLCs. Chapter 3 also discusses the reasons for variation in progress towards international objectives, and the implications for the development of a new generation of targets towards the CBD 2050 Vision for Biodiversity.

One of the innovations of the GA is to explore target-seeking scenarios related to desirable futures, possible pathways, and their trade-offs in Chapters 4 and 5. They build upon previous chapters to assess the evidence of plausible future trends (4) in nature, nature's contributions, and quality of life; and possible pathways (5) to sustainable futures.

Chapter 4 addresses the question *What are the plausible futures for nature, nature's contributions to people and their implications for a good quality of life?* It does so by considering a wide range of scenarios of direct and indirect drivers, from business-as-usual to transformative sustainability. In line with the 2030 SDGs and the CBD 2050 Vision for Biodiversity, the chapter focuses on the 2030 and 2050 timeframes, but also includes projections to the end of the 21st century. Using statistical extrapolations, exploratory scenarios of direct and indirect drivers, and inferences from patterns in case studies derived from an extensive systematic literature review, the chapter examines these trends for terrestrial, marine, and freshwater systems, including the projected impacts of climate change on them, and the relative roles of direct drivers such as climate change, atmospheric CO_2 concentration and land use in terrestrial systems. These trends are then linked to their potential impact on the Aichi Targets and the SDGs. It also addresses potential interactions and feedbacks among nature, nature's contributions, and quality of life, including possible implications for regime shift and tipping points, and adaptive capacity. The systematic review of the literature evidenced a paucity of global scale scenarios accounting for important drivers such as pollution or invasive alien species, and concerns about Indigenous Peoples and Local Communities.

Chapter 5 addresses the question *What pathways and policy intervention scenarios relating to nature, its contributions to people, and their impacts on quality of life can lead to sustainable futures?* In doing so, the chapter focuses in particular on the means of achieving internationally agreed upon goals and targets broadly related to biodiversity and ecosystem functions and their societal benefits. Building upon and expanding the literature review carried out in Chapter 4, the chapter includes a nexus analysis of pathways toward six focal clusters of SDGs, including potential synergies and trade-offs. These six foci include *feeding the world without degrading nature on land* (SDGs 15, 2, 12), *meeting climate goals while maintaining nature and its contributions to people* (SDGs 7, 2, 13, 15), *conserving and restoring nature on land while contributing positively to human well-being* (SDGs 15, 3), *maintaining freshwater for nature and humanity* (SDGs 6, 2, 12), *securing food provisioning and nature protection in oceans and coasts* (SDGs 14, 2, 12), and *resourcing growing cities while maintaining the nature that underpins them* (SDGs 11, 15). The chapter then synthesizes cross-cutting findings from the nexus analysis and integrates other broad and diverse scholarship on social transformation to derive common constituents of sustainable pathways, using the metaphor of 'levers' and 'leverage points' of societal change. These interventions and points of intervention together lay out bold but achievable pathways to deep and lasting change that would sustain and improve the state of nature and human quality of life in the coming century.

Finally, Chapter 6 addresses the question *What are the opportunities and challenges, as well as options available to decision makers, at all levels relating to nature, its contributions to people, and their impacts on quality of life?* Building upon previous chapters, and closely aligned with the nexuses and pathways discussed in Chapter 5, this chapter focuses on assessing opportunities and challenges for decision makers at all levels to engender transformative change by integrating governance approaches that are integrative (addressing policy incoherence), inclusive (advancing mechanisms that enable participation), informed (based on legitimate and credible knowledge), and adaptive (governance that enables learning). This analysis provides a framework to examine transformative governance of five overarching issues following the discussion of pathways and levers in Chapter 5. These include integrated approaches applied to sustainable management and conservation of landscapes, coastal and marine areas, freshwater systems, cities and urban areas, and energy and infrastructure. In each case, the chapter examines the advances and setbacks of existing policy instruments, their implications for different stakeholder groups, and further advances needed to address current and emerging governance challenges. Finally, the chapter pays attention to factors affecting transformations towards sustainable economies, including the role of societal values behind economic development models, distortions and disparities in trade, tackling inequalities, developing more inclusive economic accounting, and improving financing for biodiversity and the environment.

In addition to the main body of each chapter, an extensive set of Supplementary Material is available, providing further information and preserving relevant supporting evidence and documentation.

1.2 THE IPBES GLOBAL ASSESSMENT IN THE CONTEXT OF OTHER ASSESSMENTS

The GA is part of a lineage of environmental assessments, and as such it builds upon the experiences and rules of practice of previous assessments of the global environment, biodiversity and ecosystem services, oceans and climate change, including four notable assessment reports completed on a global scale with strong focus on environmental change, biodiversity and ecosystem services, namely the Global Environmental Outlook Series (GEO), the Global Biodiversity Assessment (Heywood & Watson, 1995), the Millennium Ecosystem Assessment[2] (MA 2005), and the Global Biodiversity Outlook (GBO) and the Local Biodiversity Outlook (LBO) series. Benefiting from this rich heritage, the GA is also innovative on several fronts (**Box 1.1**: The global assessment innovative approach).

Efforts to develop evaluations of the global environment date back to the 1960s, benefiting from pioneer initiatives such as the International Biological Program (IBP), which set out a collaborative and international research agenda seeking to understand the 'biological underpinnings of productivity and human welfare'. IBP also influenced the creation of UNESCO's Man and Biosphere program in 1971 and its vision to bring together natural and social sciences to collaborate on understanding human-environment relationships. The 1972 Club of Rome's "The Limits to Growth" report and *World3* simulation model had a major influence on both global sustainability thinking and analytical approaches to global level human-environmental analysis; *World3* pioneered modelling interactions between scenarios of population, economic, and industrial growth, food production and resource uses, and limits to global ecological systems. During the 1980s, numerous initiatives emerged, among others, the Worldwatch Institute State of the World report series (starting in 1984), the World Conservation Strategy report developed by UNEP, IUCN, and WWF (starting 1980), and the influential Brundtland report 'Our Common Future' (1987).

Equally important to our current understanding of global environmental and climate change, and global sustainability more broadly, were the emergence of international research networks and programs since 1980. In just over a decade, under the auspices of various international organizations, four main research programs emerged, the World Climate Research Program (WCRP), the International Geosphere Biosphere Program, DIVERSITAS, and the International Human Dimensions Program (IHDP). Later, these programs

2. https://www.millenniumassessment.org/en/About.html

collaborated on cross-cutting issues through the integrated Earth Systems Science Partnership (ESSP), eventually coming together within the current Future Earth program. Under their umbrellas, research projects/programs covering virtually all aspects of human-environment interaction developed, many of which continue to flourish today. These programs and projects continue to provide scientific knowledge and conceptual underpinnings which have been key to efforts such as, among many others, the IPCC and IPBES.

The first comprehensive large-scale international biodiversity assessment was the Global Biodiversity Assessment (Heywood & Watson, 1995), which was proposed in 1992 in an effort to, for the first time, mobilize the scientific community to evaluate the global status of biodiversity. This endeavor was initiated by the Global Environment Facility (GEF)'s Scientific and Technical Advisory Panel (STAP) and overseen by UNEP. The GBA, however, was not an intergovernmental process and did not have a mechanism for involving multiple stakeholders, including decision-makers; which limited its policy reach even though the assessment included policy implications (Watson & Gitay, 2007).

At the turn of the millennium, in response to biodiversity-related conventions (e.g., Convention on Biological Diversity [CBD], Ramsar Convention on Wetlands, the Convention on Migratory Species, [CMS], Convention to Combat Desertification [UNCCD]) and a request by the United Nations Secretary-General (2000)[3], another major, one-time global assessment centered on the relationship between ecosystem services and human well-being was initiated: the Millennium Ecosystem Assessment (MA). The MA, completed in 2005, covered the status and trends in biodiversity, ecosystems and their services, plausible future scenarios, and options for action, and a series of sub-global assessments, which continued after the publication of the MA. Although its external review included governments as well as experts, and its board included representatives of end user groups such as biodiversity-related conventions, UN agencies, business, some national governments and civil society, the MA is considered a non-governmental assessment as its key findings were formally approved by their board, not by governments. The legacy of the MA has been major in mainstreaming the relationship between ecosystem services and human wellbeing and in motivating international interdisciplinary collaborations. It also spurred an array of sub-global assessments, along with many other regional and thematic assessments carried out since 2000. Equally important, the MA motivated the emergence of The Economics of Ecosystems and Biodiversity program (TEEB), bringing together in particular economics and ecological sciences to advance the understanding of values of ecosystem services, using sectoral and cross-sectoral analyses, bringing attention to their importance to national economies (Kumar, 2010). TEEB has had both important impacts in the mainstreaming of ecosystem services in public policies and in advancing approaches and conceptualization of values in ecosystem services analyses.

Two other relevant global-level reports are the Global Biodiversity Outlook (GBO) series, CBD's flagship reports, and the Global Environmental Outlook (GEO) series, UNEP's flagship report. The GBO was initiated at the second meeting of the Conference of the Parties of the CBD (COP-2), which requested a periodic report on biological diversity providing a summary of the status of biological diversity and effectiveness of implementation measures for safeguarding biodiversity. The first edition of the GBO series was published in 2001 with their key end users being decision-makers involved in the implementation of the Convention (CBD). The GBO-5 report, to be released in 2020, will consider the IPBES global assessment as a major input. UNEP's GEO reports were initiated in 1995 at the request of member states in response to UN Agenda 21[4] and its reporting requirements, and as a response to the Brundtland report. Since its first volume in 1997, to date, five GEO reports have been published and the GEO sixth edition (GEO-6) delivered in March 2019.

In addition to the assessments mentioned above, the GA shares many features in terms of procedures, with the Intergovernmental Panel on Climate Change (IPCC) assessments. The IPCC was created 30 years ago under the joint auspices of the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP), and its first assessment report was delivered to Governments in 1990. IPBES assessments procedurally mirror those of IPCC, as IPBES rules of procedure for the preparation of deliverables (i.e., decision IPBES 3/3) are transposed from the Intergovernmental Panel on Climate Change (IPCC)[5]. While the structure of IPCC assessments differs slightly, in general these two intergovernmental assessment processes are very similar. These similarities stem from the fact that, like the IPCC, the assessment work of IPBES is mandated in response to governments' requests; it aims to inform decision-makers through policy-relevant, not policy-prescriptive statements and findings.

3. https://www.millenniumassessment.org/en/About.html

4. Agenda 21 is a comprehensive plan of action to be taken globally, nationally and locally by organizations of the United Nations System, Governments, and Major Groups in every area in which human impacts on the environment. Agenda 21, the Rio Declaration on Environment and Development, and the Statement of principles for the Sustainable Management of Forests were adopted by more than 178 Governments at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil, 3 to 14 June 1992. https://sustainabledevelopment.un.org/outcomedocuments/agenda21. Accessed May 2018.

5. Procedures for the preparation, review, acceptance, adoption, approval and publication of IPCC reports – Appendix A to the Principles Governing IPCC Work (https://archive.ipcc.ch/pdf/ipcc-principles/ipcc-principles-appendix-a.pdf)

The roles of experts are similar, authors are regionally represented, and each assessment undergoes two external review rounds prior to the submission of the final government draft. In both cases, the resulting Summary for Policymakers (SPM) is negotiated in their respective plenaries among member countries. IPBES' mandate includes three functions in addition to assessments: capacity building, knowledge generation catalysis and policy support (Brooks *et al.*, 2014). Distinctively, IPBES also has an explicit mandate to embrace different knowledge systems in its assessments and functions.

The GA had seven IPBES assessments to draw from (i.e., synthesize information from) and build upon which included two thematic assessments (pollination and land degradation and restoration), one methodological assessment (scenarios and models), and four regional assessments: Americas, Africa, Europe and Central Asia, and Asia and the Pacific. Because the four regional assessments and the land degradation and restoration assessment were being undertaken almost in parallel (completed in 2018) – this meant the global assessment had the unique advantage and benefit of accessing a separate and extensive up-to-date pool of evidence (albeit somewhat overlapping) and experts that could confirm, support or contribute to the evaluations and work completed in the global assessment.

Box 1 1 **The global assessment innovative approach.**

The IPBES global assessment is the **first independent comprehensive global assessment of biodiversity, ecosystems and their contributions to people following an intergovernmental process from start to end**, as such, this assessment is **highly policy relevant** having its mandate and scope requested and approved by governments and international conventions. In addition, the geographic, gender and disciplinary **balance** of the author team has further increased this assessment's legitimacy. The global assessment is built on the innovative and inclusive **IPBES conceptual framework** explaining connections between people and nature (see Section 1.3.1 and **Box 1.2**) with institutions, governance and other indirect drivers being central to all interactions. The global assessment also made a concerted effort to include a diversity of **worldviews and knowledge systems including systematic analyses of evidence on indigenous and local knowledge and issues**, and dialogue meetings involving experts and representatives from Indigenous Peoples and Local Communities (see Section 1.3.2 and **Box 1.3** and **1.4**). The IPBES global assessment has recognized thresholds, synergies, trade-offs and feedbacks in its assessment of nature, nature's contributions to people and drivers of their changes through the concepts of **telecoupling and nexuses** – which has not been done before at the global scale; understanding these interactions (spatially and across sectors) have direct implications for considering options for action. Framed around major international agreements such as the aforementioned post-2020 biodiversity framework of the UN Convention of Biological Diversity, the Paris Agreement of the UN Framework Convention on Climate Change and the UN 2030 Agenda for Sustainable Development and its Sustainable Development Goals **– the global assessment aims to be far-reaching and to inform decision makers and end users at all scales and sectors**. The completion of this global assessment is uniquely timed to be a major input to the Convention on Biological Diversity's fifth edition of the Global Biodiversity Outlook and its second edition of the Local Biodiversity Outlook. The global assessment has assessed progress towards the current Aichi Biodiversity Targets which will inform the next set of targets and the post-2020 biodiversity framework.

1.3 THE CONCEPTUAL BASES OF THE IPBES GLOBAL ASSESSMENT

1.3.1 The IPBES Conceptual Framework

As previous IPBES assessment reports, this global assessment is structured according to the IPBES conceptual framework (CF), described in detail in Díaz *et al.* (2015a, 2015b). The CF is a highly simplified model of those interactions between people and the rest of the fabric of life on Earth that are most relevant to IPBES's goal. It intends to bring together the perspectives and information of a wide spectrum of knowledge systems and stakeholders on the status and trends of the living world and its contributions to people's quality of life. Since its inception by approval of the IPBES member countries in 2013, the CF has provided a conceptual and analytical tool that underpins all IPBES functions and provides a consistent structure and terminology to IPBES products at different spatial scales, on different themes, and in different regions. To date, it has been used successfully to guide the IPBES pollination assessment (IPBES, 2016a), the methodological assessments on scenarios and models (IPBES, 2016b), four regional assessments (IPBES, 2018b, 2018c, 2018d, 2018e), the land degradation and restoration assessment (IPBES, 2018a), and the present global assessment.

The CF includes six primary interlinked elements (or components) that operate at various scales in time and space: nature; nature's contributions to people (NCP); anthropogenic assets; institutions and governance systems and other indirect drivers of change; direct drivers of change; and good quality of life **(Box 1.2, Figure 1.2)**. These elements have been conceived as broad, inclusive categories that should be meaningful and relevant to all stakeholders involved. The CF thus provides a common ground and terminology to facilitate cross-disciplinary and cross-cultural understanding and inter-operability in the discussion of problems and the identification of solutions to common challenges.

The CF explicitly considers that formal and informal institutions mediate human-nature interactions, facilitating or hindering the co-production of NCP and the distribution of benefits to different social groups. Built upon a long lineage of conceptual frameworks, intended to facilitate interdisciplinary collaboration and science-policy dialogues, salient innovative aspects of the IPBES CF are its participatory construction and its explicit consideration of diverse disciplines, as well as diverse stakeholders (the scientific community, governments, international organizations, civil society at different levels, with Indigenous Peoples and Local Communities sometimes being part of each of these groups), and their different knowledge systems (natural sciences, social sciences and humanities, indigenous, local and practitioners' knowledge).

Particularly relevant features of the CF are:

- **Institutions and governance:** In a shift of focus with respect to most previous initiatives, the CF highlights the central role of institutions (in the broadest sense) as key indirect drivers of change and more generally as fundamental mediators of the perceptions and values about nature and NCP as well as the relationships between humans and all other forms of life on Earth.

- **Explicit consideration of different knowledge systems:** The different knowledge systems from which each of the major elements can be approached are graphically indicated using different fonts and colours for the boxes representing the main elements in **Figure 1.2**. The headlines in larger black bold font indicate the broad, highly inclusive categories nature, nature's contributions to people (NCP), good quality of life (GQL), indirect drivers, direct drivers and anthropogenic assets. The green and blue fonts indicate the more specific categories used by different disciplines and knowledge systems to refer to them. In green are some examples of common natural and economic sciences categories, and in blue, some from indigenous knowledge systems. It is important to stress that these are simply illustrations of the many categories that could be used, and that between the green and blue categories there is a wide gradient of perspectives rather than a sharp distinction. Therefore, the clear-cut distinction between the blue and green 'circuits' in the diagram is simply a means to highlight the importance of incorporating diverse perspectives into the CF.

- **Co-production of nature's contributions to people (also called joint production in Chapter 2-nature's contributions to people – NCP):** highlights the role of human societies as co-producers of NCP through anthropogenic assets (e.g., labour, knowledge, financial and built assets). This is a change in emphasis with respect to some conservation approaches that tended to see humans almost exclusively as external drivers negatively impacting nature. From a cultural perspective, co-production of NCP also provides shared meaning in society of the way interactions with nature contribute towards a good quality of life.

- **Plurality of values and interests:** The explicit recognition that there are no uniform needs (beyond those involved in physical survival), aspirations, perceptions, or preferences towards nature and NCP across the whole humankind, but rather a highly uneven, complex, constantly evolving mosaic of views, interests and stakes across and within societies. See Section 1.3.1.3.

The adoption of a single CF at the onset of IPBES was made in full recognition that a perfect alignment among the categories of different knowledge systems or even disciplines is unattainable. Representations of human–nature relationships may vary across cultures and knowledge systems in relation to specific worldviews and epistemologies, including between natural and social sciences and the humanities, scientific and indigenous knowledge systems, as well as among Indigenous Peoples and Local Communities. The CF is therefore mainly intended to provide a common platform for reflection and identification of options, rather than a comprehensive shared cross-cultural description of the world.

Box 1.2 describes the main elements of the CF, their interlinkages and the recognition of different knowledge systems as diagrammatically presented in **Figure 1.2**. A full glossary is presented as Supplementary Material 1.1.

Box 1 2 **The Main Elements of the IPBES Conceptual Framework.**

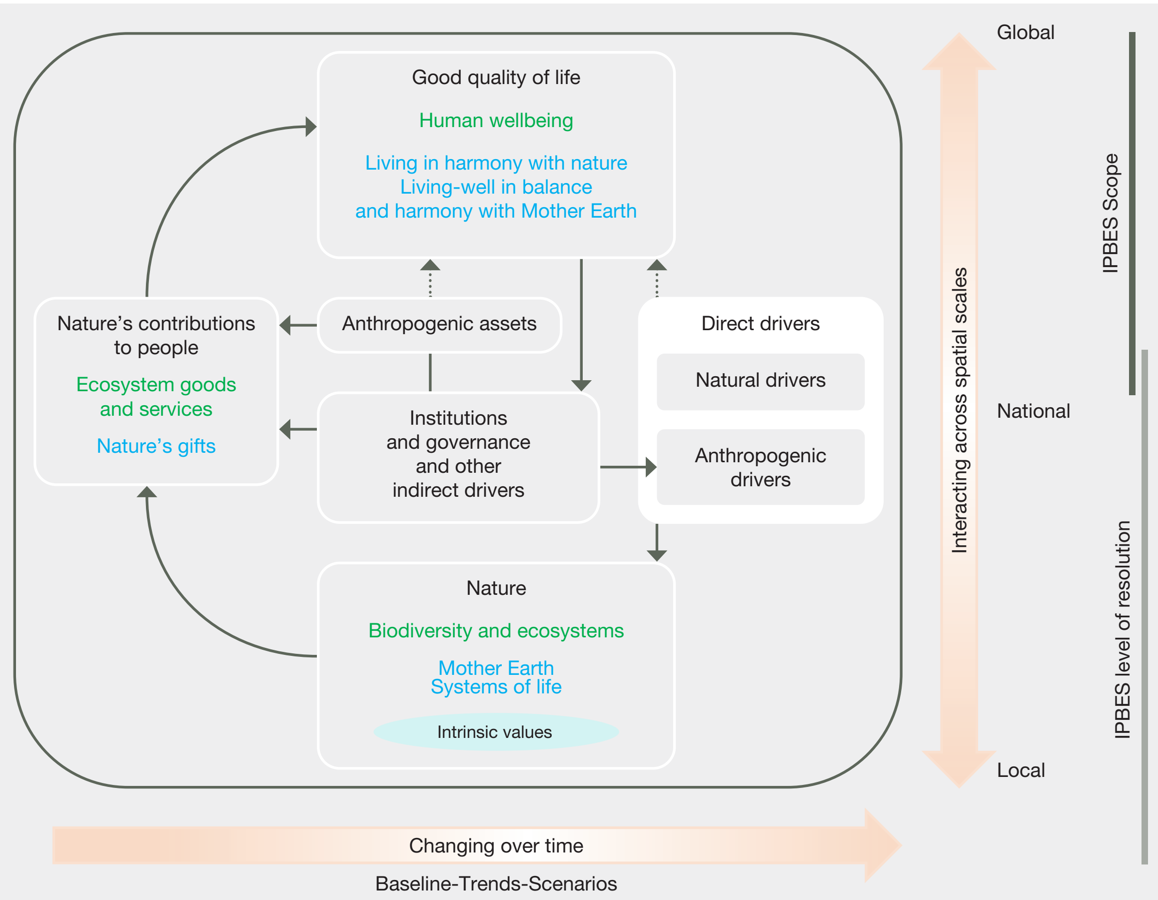

Figure 1 2 **The IPBES conceptual framework (CF). Source: Díaz *et al.* (2015a, 2015b).**

The IPBES conceptual framework is a highly simplified model of the complex interactions between the natural world and human societies. The model identifies the main elements (boxes within the main panel outlined in white), together with their interactions (arrows in the main panel), that are most relevant to the Platform's goal. "Nature", "nature's contributions to people" and "good quality of life" (indicated as black headlines and defined in each corresponding box) are inclusive categories that were identified as meaningful and relevant to all stakeholders involved in IPBES during a participatory process, including various disciplines of the natural and social sciences and the humanities, and other knowledge systems, including those of Indigenous Peoples and Local Communities. Text in green denotes scientific concepts, and text in blue denotes concepts originating in other knowledge systems. The solid arrows in the main panel denote influence between elements, and dotted arrows denote links that are acknowledged as important, but that are not the main focus of the Platform. The thick coloured arrows below and to the right of the central panel indicate the scales of time and space, respectively. The intrinsic values of nature (represented by a blue oval at the bottom of the nature box) are interpreted as being independent from human experience and thus do not participate in these arrows (see Section 1.3.1.3). See Supplementary Material 1.1 for glossary, and Díaz *et al.* (2015a) for further explanation and examples of the links indicated by the different arrows.

This conceptual framework was accepted by the Plenary in decision IPBES/2/4, and the Plenary took note of an update presented in IPBES/5/INF/24 and in decision IPBES/5/1. Further details and examples of the concepts defined in the box can be found in the glossary.

- **Nature:** (also referred as "living nature") the nonhuman world, including coproduced features, with particular emphasis on living organisms, their diversity, their interactions among themselves and with their abiotic environment. Within the framing of the natural sciences (context of science), nature include e.g., all dimensions of biodiversity, species, genotypes, populations, ecosystems, the biosphere, ecosystem functioning, communities, biomes, Earth life support's systems, and their associated ecological, evolutionary, biogeochemical processes and biocultural diversity. Within the framework of economics, it includes categories such as biotic natural resources, natural capital and natural assets. Within a wider context of social sciences and humanities and interdisciplinary environmental sciences, it is referred to with categories such as natural heritage, living environment, or the nonhuman. Within the context of other knowledge systems, it includes categories such as Mother Earth (shared by many IPLCs around the world), Pachamama (South American Andes), se¯nluo´-wa`nxia`ng and tien-ti (East Asia), Country (Australia), fonua/vanua/whenua/ples (South Pacific Islands), Iwigara (Northern Mexico), Ixofijmogen (Southern Argentina and Chile), among many others (see Díaz *et al.*, 2015a for references). Other (non-living) components of nature, such as deep aquifers, mineral and fossil reserves, and wind, solar, geothermal and wave power, are not the focus of the Platform. The degree to which humans are considered part of nature varies strongly across these categories (see Section 1.3.1.1). Many aspects of biocultural diversity (see glossary) are part of nature, while some others pertain more to what in the CF is defined as NCP and anthropogenic assets.

- **Anthropogenic assets** refer to knowledge (including indigenous and local knowledge and technical or scientific knowledge), health facilities, technology (both physical objects and procedures), work, financial assets, built-up infrastructure, among others, that, together with nature, are essential in the co-production (or joint production) of nature's contributions to people (NCP) (Díaz *et al.*, 2018; Palomo *et al.*, 2016; Reyers *et al.*, 2013). Within some cultural contexts, this co-production also involves mutual responsibility (e.g., Comberti *et al.*, 2015; Von Heland & Folke, 2014). Anthropogenic assets have been highlighted to emphasize that a good life is achieved by a co-production of benefits between nature and societies.

- **Nature's contributions to people** (NCP) are all the contributions of nature, both positive and negative, to the quality of life of humans as individuals, societies or humanity as a whole. In earlier versions of the CF, this dimension was referred to as nature's benefits to people (NBP), with exactly the same meaning; the term was changed to better reflect that it includes negative contributions (detriments) as well positive contributions (benefits). See section 1.3.1.1 for further details.

- **Drivers of change** refer to all those external factors that affect nature, and, as a consequence, also affect the supply of NCP. The CF includes drivers of change as two of its main elements: indirect drivers (all anthropogenic) and direct drivers (both natural and anthropogenic).

- **Direct drivers**, both non-human induced and anthropogenic, affect nature directly in a physical sense. Direct anthropogenic drivers are those that flow from human institutions and governance systems and other indirect drivers. They include positive and negative effects, such as habitat conversion, human-caused climate change, or species introductions. Direct non-human induced drivers can directly affect anthropogenic assets and quality of life (e.g., a volcanic eruption can destroy roads and cause human deaths), but these impacts are not the main focus of IPBES. See Supplementary Material 1.3 for a detailed typology of drivers.

- **Indirect drivers** are human actions and decisions that operate diffusely by altering and influencing direct drivers as well as other indirect drivers. They do not physically impact nature or its contributions to people. Rather, they are the root causes of the direct anthropogenic drivers that affect nature both positively and negatively. Indirect drivers include e.g., economic, demographic, institutional, technological and cultural ones. Special attention is given, among indirect drivers, to the role of institutions and governance systems, including formal and informal systems of access to land and property rights as related to any component of nature, socially shared rules, legislative arrangements, international regimes such as agreements for the protection of endangered species, and economic policies. See Supplementary Material 1.3 for a detailed typology of drivers.

- **Institutions and governance systems and other indirect drivers** are the ways in which societies organize themselves and the resulting influences on other components. They are the underlying causes of environmental change that are exogenous to the ecosystem in question. Because of their central role, influencing all aspects of human relationships with nature, they are key levers for decision-making. "Institutions" encompasses all formal and informal interactions among stakeholders and the social structures that determine how decisions are taken and implemented, how power is exercised, and how responsibilities are distributed. To varying degrees, institutions determine the access to and control, allocation and distribution of the components of nature and of anthropogenic assets and their contributions to people. Examples of institutions are systems of property and access rights to land (e.g., public, common-pool or private), legislative arrangements, treaties, informal social norms and rules, including those emerging from indigenous and local knowledge systems, and international regimes such as agreements against stratospheric ozone depletion or for the protection of endangered species of wild fauna and flora. Economic policies, including macroeconomic, fiscal, monetary or agricultural policies, play a significant role in influencing people's decisions and behaviour and the way in which they relate to nature in the pursuit of benefits. However, many of the drivers of human behaviour and preferences, which reflect different perspectives on a good quality of life, work largely outside the market system.

- **Good quality of life (GQL)** is the achievement of a fulfilled human life. It is a highly value-laden and context-dependent concept comprising multiple factors such as access to food, water, health, education, security, and cultural identity, material prosperity, spiritual satisfaction, and freedom of choice. A society's achievement of good quality of life (GQL) and the vision of what this entails strongly influences institutions and governance systems and other indirect drivers and, through them, all other elements in the CF. The vision of what a good quality of life entails also indirectly shapes, via institutions, the ways in which individuals and groups relate to nature. Likewise, institutions and governance systems reflect and can influence a society's value system and perception of what constitutes good quality of life. IPBES does not directly address this aspect of the CF in its assessments so far, but actions that governments and societies may choose to take based on the findings of the IPBES assessments often require addressing this pathway wisely. Visions, concepts and indicators of a good quality of life are highly diverse, both in cultural roots and in geographical application. Approaches applied internationally can be based on economic (e.g., gross domestic product per capita), combined economic and social (e.g., human development index, inclusive wealth) or holistic framings (living in harmony, gross national happiness index). Other approaches, more culturally specific and place-based, include e.g., Sumak Kawsay/ Buen vivir (Central Andes), teko porã (Paraguay), vida plena (Amazonian basin), shizen kyosei shakai (Japan). See Díaz *et al.* (2015a) for references.

1.3.1.1 The Nature's Contribution to People (NCP) concept and analytical framework

Nature's contributions to people (NCP), one of the six major inclusive elements of the IPBES conceptual framework (Díaz *et al.*, 2015a, 2015b; IPBES, 2014, 2017), are all the contributions, both positive and negative, of living nature (i.e., all organisms, ecosystems, and their associated ecological and evolutionary processes) to people's quality of life (Díaz *et al.*, 2018). Beneficial contributions include, e. g., food provision, water purification, and artistic inspiration, whereas aspects of nature that can be negative to people (detriments) include e.g., disease transmission and predation that damage people or their assets. Overall, the values of nature's contributions are overwhelmingly positive as they sustain people's quality of life. However, the CF explicitly recognizes potentially detrimental NCP, and the fact that generally NCP are not inherently positive or negative, but rather this depends on spatial, temporal, social or cultural context (Ango *et al.*, 2014; Rasmussen *et al.*, 2017; Saunders & Luck, 2016; Shapiro & Báldi, 2014). What constitutes a benefit or a detriment can change with time, even for the same person, given e.g., a change in socio-economic circumstances that may alter the importance assigned to a given NCP, often a given biological entity can be at the same time a source of positive and negative contributions (Rasmussen *et al.*, 2017). This is important for conceptual and practical reasons. For example, while we are still striving to document and highlight the positive contributions (benefits) we derive from nature, many of the detriments (e.g., vector-borne diseases, livestock attacks by predators, agricultural pests) have long been recognized, valued in terms of their impacts on people, and incorporated into policy decisions. Furthermore, what are generally considered positive contributions sometimes reflect the view of dominant social actors and ignore the fact that the same contribution may be perceived as being negative in the view of less powerful sectors of society (Cáceres *et al.*, 2015). This highlights the relevance of identifying trade-offs that occur among and within many NCP as well as social trade-offs. Conflict tends to arise when negative NCP experimented by some social actors are mediated or exacerbated by decisions taken by other actors.

NCP recognizes a wide range of descriptions of the human dependence on living nature. One of such descriptions is through the concept of ecosystem goods and services (considered either separately or in bundles), pioneered in the science-policy interface by the Millennium Ecosystem Assessment (2003, 2005). The concept of NCP embraces the thriving field of ecosystem service science – in itself heterogeneous in terms of existing internal framings (Chaudhary *et al.*, 2015; Droste *et al.,* 2018) – together with a diversity of other descriptions that, although perhaps not as visible in the fields of mainstream environmental sciences, are foundational in other fields of knowledge and schools of thought, especially in the social sciences and humanities, and underpin values, decisions and practices throughout the world (Turnhout *et al.*, 2013). The range of descriptions of the human dependence of living nature contemplated in the NCP approach is thus vast. On one extreme, nature is seen as a stock of natural capital (or natural assets) from which goods and services flow to humans unidirectionally (e.g., timber provided by forests) in the form of an ecological production function (reviewed in Polasky & Segerson, 2009). The flow depends on human agency and also on the existing physical and biological conditions needed for the persistence of the biological entity from which the flow originates. Improving or sustaining the condition of the biological entity would be akin to investing in natural capital from which an interest would accrue to society, i.e., the flow of goods and services. Maintaining the productive potential of the stock of natural capital to sustain the flow of services to society would be seen as an intergenerational social objective. On the other extreme are descriptions where both people and other biophysical entities are seen as having agency and being inextricably linked by reciprocal ties of mutual care and obligations (e.g., Berkes, 2012; Descola, 2013; Head, 2008; Ingold & Pálsson, 2013; Whatmore, 2006), described with e.g., the term nature's gifts used by many indigenous and non-indigenous cultures (Hill *et al.*, 2016), or services-to-ecosystems in some hybrid framings (Comberti *et al.*, 2015). The notion of nature's contributions to people is intended to embrace and include, rather than replace and exclude the abovementioned descriptions and any others in between.

A gradient of perspectives on human dependency on nature – implications for reporting

Within the context of an assessment report, a reporting system is the method of collecting, storing and synthesizing information and knowledge, and communicating findings. It should allow the re-organization and simplification of heterogeneous content from diverse sources in a way which is consistent, repeatable and easily communicable to a wide range of audiences. Specifically, the IPBES reporting system (Díaz *et al.*, 2018; Decision IPBES-5/1) contemplates a gradient of complementary approaches through which to give meaning to NCP, ranging from a generalizing to a context-specific perspective. While presented here as extremes of such a gradient for description purposes (see previous paragraph), these two perspectives do not have clear-cut limits; they are often blended and interwoven in the process of problem framing and knowledge generation and, although sometimes a particular study, field situation, research question or assessment undertaking is squarely placed within either a generalizing or a context-specific perspective, situations with a mixture of both are not uncommon (Berger-González *et al.*, 2016; Brondizio, 2017; Chilisa, 2017; Tengö *et al.*, 2017) **(Figure 1.3a)**.

Generalizing perspective: Typical of the scientific literature that has formed the basis of most large-scale environmental assessments, this perspective (represented in green at the bottom of **Figure 1.3a**) is fundamentally analytical in purpose; it seeks a universally applicable set of categories of flows from nature to people. Distinction between them intends to be sharp, following the traditions of culture-nature dichotomy, and agency tends to be attributed to people only. NCP categories can be seen at finer or coarser resolution, but can still be organized into a unified, self-consistent system. IPBES identifies 18 such categories for reporting NCP within the generalizing perspective, organized in three partially overlapping groups, defined according to the type of contribution they make to people's quality of life: regulating, material and non-material NCP.

- *Nature's material contributions to people* refers to substances, objects or other material elements from nature that sustain people's physical existence and the infrastructure (i.e., the basic physical and organizational structures and facilities, such as buildings, roads, power supplies) needed for the operation of a society or enterprise. They are typically physically consumed in the process of being experienced, such as when plants or animals are transformed into food, energy, or materials for clothing, shelter or ornamental purposes.

- *Non-material* contributions are nature's effects on subjective or psychological aspects underpinning people's quality of life, both individually and collectively. The entities that provide these intangible contributions can be physically consumed in the process (e.g., animals in recreational or ritual fishing or hunting) or not (e.g., individual trees or ecosystems as sources of inspiration). Examples include forests and coral reefs providing opportunities for recreation and inspiration, or particular organism (animals, plants, fungi) or habitat (mountains, lakes) being the basis of spiritual or social-cohesion experiences.

- *Nature's regulating contributions to people* refers to functional and structural aspects of organisms and ecosystems that modify the environmental conditions experienced by people, and/or sustain and/or regulate the generation of material and non-material contributions. For example, these contributions include water purification, climate regulation and the regulation of soil erosion.

Building on the insights of the social sciences and the humanities, the NCP approach acknowledges that culture is the lens through which all the elements of nature are perceived and valued. In other words, culture permeates through and across all three broad NCP groups, rather than being confined to an isolated category, i.e., there is no "cultural" or "non-cultural" NCP. In addition, the three broad groups explicitly overlap, implying that many of the 18 NCP categories do not squarely fit into any one of the broader NCP groups **(Figure 1.3b)**, although they may be distinguished for practical reporting reasons. Material and non-material NCP are often interlinked in most, if not all, social-cultural contexts (Chan *et al.*, 2012b). For example, food can be primarily considered as a material NCP because calories and nutrients are essential for physical sustenance, but food is also full of symbolic meaning well beyond physical survival, having other less tangible impacts on people's quality of life. The cultural lens largely determines to what degree food is a non-material contribution as well as a material one and how both types of NCP are valued.

The 18 NCP defined by IPBES under the generalizing perspective (**Figure 1.3a**, see Supplement 1.2 for more details and examples) are in some cases sharply defined contributions, and in some others represent bundles of similar contributions. They were identified through a participatory process based on several pre-existing classifications at the global and regional scales (Haines-Young & Potschin, 2013; Kumar, 2010; Millenium Ecosystem Assessment, 2005; UK National Ecosystem Assessment, 2011), as well as recent empirical and conceptual advances in ecological, social and anthropological sciences.

Context-specific perspective: Represented in blue at the top of **Figure 1.3a**, this perspective is typical, but not exclusive, of indigenous and local knowledge systems; here knowledge production does not explicitly seek to extend or validate itself beyond specific spatial contexts (Smith, 1999; Tengö *et al.*, 2017). Put differently, this perspective does not always contribute to, and may be difficult to align with more generalizing goals of attaining a universally applicable schema. While internally consistent, the categories are context-specific and usually not intended to be universally applicable. However, no acceptable standard classification or schema (equivalent to **Figure 1.3b**) is currently available, and designing or imposing one may be inappropriate (e.g., Smith, 1999). The context-specific perspective may instead present NCP as bundles that follow from distinct social-cultural practices, language and lexicon, and ethnoecological knowledge associated with forms of interaction with the environment, such as fishing, farming or hunting, including the spiritual significance encoded in places, organisms or entities such as sacred or otherwise protected trees, animals or landscapes (Berkes, 2012; Descola, 2013; Hill *et al.*, 2016). This may involve different degrees of human and non-human relationships expressed in terms of kinship and reciprocal care and obligations (Berkes, 2012; Comberti *et al.*, 2015; Hill *et al.*, 2016; Salmón, 2000; Surrallés & García Hierro, 2005; Von Heland & Folke, 2014).

The evidence produced through a particular framing, such as ecosystem goods and services, environmental services, ecological production functions stemming from natural capital, nature's gifts, or practices of care, can be aligned under the NCP framing, either within the 18 categories of the generalized perspective (which connects easily with classic ecosystem services categories, as done in e.g., the IPBES regional assessments), or by the use of context-specific descriptions (e.g., Supplementary Material 2 in Díaz *et al.*, 2018), or a combination of both (e.g., Hill *et al.*, 2016). In doing so, the NCP approach does not ignore or invalidate any pre-existing approach or metric used by different communities of practice. For example, it welcomes ecosystem services and their economic dimensions; but at the same time acknowledges that there are other ways of framing and engaging with the benefits or detriments from nature that results from different cognitive models about the links between people and the rest of the living world (Muradian & Pascual, 2018). Despite often deeply different descriptions, relations and causalities, the conclusions from such different knowledge systems and perspectives can often coincide or complement each other when it comes to searching for solutions.

The NCP reporting system thus allows the harnessing of pre-existing information, information that is being produced at the moment, or will be produced in the future, within the specific framings of different communities of practice, including those associated with ecosystem services, ethnoecology, environmental conservation, political ecology, etc. into a pluralistic and inclusive common ground. This gives the NCP reporting system maximum flexibility, because it avoids leaving the vast diversity of human-nature perspectives and descriptions out of the picture or shoe-honing them into pre-established categories and classifications that may deprive them of meaning to different stakeholders. By doing so it also accommodates different epistemic communities to collaborate in enlarging the existing knowledge base for sustainability (Pascual & Howe, 2018), to enrich each other in more level-field interactions (Tengö *et al.*, 2017), and to be leveraged in assessing the state of, and future options for nature and its benefits and risks to societies.

1.3.1.2 Evolution of thinking, approaches and terminologies on the links between nature and its contributions to people's quality of life

Like most of integrative frameworks, the CF builds on pre-existing structures and originates in the context of particular intellectual, social and political circumstances. The CF explicitly recognizes rooting in the Millennium Ecosystem Assessment (2003, 2005), its most immediate antecedent in terms of broad conceptual scope and intent. Early in the process of building IPBES, it became clear that Millennium Ecosystem Assessment framing, although useful and the

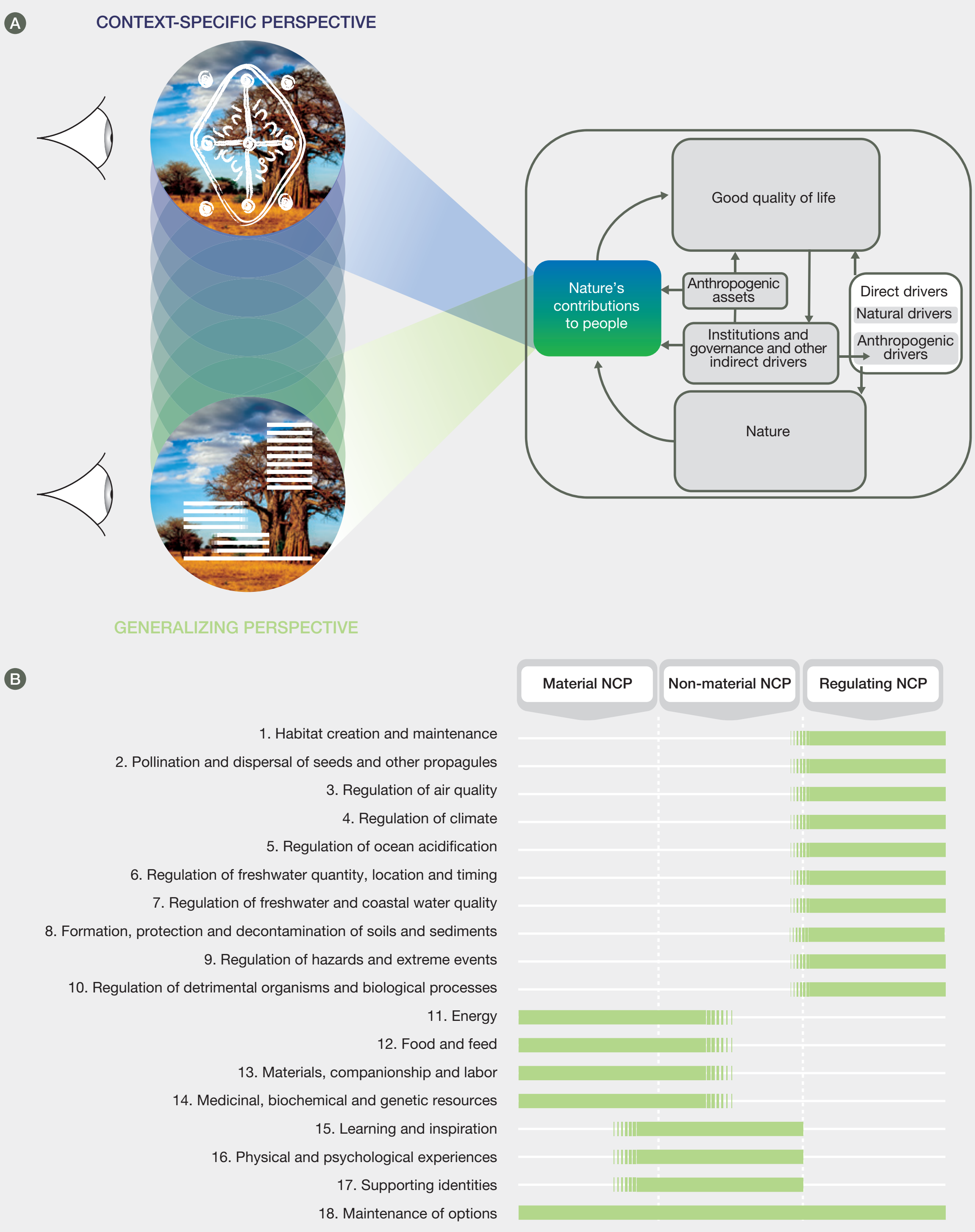

Figure 1 3 **The nature's contribution to people (NCP) approach and reporting system.**

A Two perspectives on nature's contributions to people (NCP) [Source: Díaz et al. (2018)]. NCP can be seen from the generalizing (green, bottom) or from the context-specific perspectives (blue, top). From a more generalizing perspective, 18 NCP are distinguished and organized in three broad groups – material, non-material and regulating– of general applicability (represented by the white-line figure overlapping the landscape at the bottom, shown in full in B. From a context-specific perspective these more universally applicable categories may or may not be meaningful depending on the issue and/or context. For example, a symbolic domain, such as the Warlpiri perspective on nature-human relationships (represented in a highly simplified version by white-line figure overlapping the landscape at the bottom) is only one of very many possible context-specific framings of NCP. The Warlpiri explanation of a given ecological process, however, may have significant overlap with other explanations, including a scientific one. Therefore, it is important to consider these two extremes, generalizing and context-specific perspectives, as part of a gradual transition with many potential points of overlap. Depending on the context, a stakeholder can report a specific NCP as part of any of the 18 NCP in the generalizing perspective, as part of a bundle of context-specific NCP or as transitional between the two. B The 18 NCP reporting categories used in IPBES assessments mapped onto three broad groups distinguished within the generalizing perspective [Source: Díaz *et al.* (2018)]. See main text of Section 1.3.1.1 for description of the broad groups, and chapter 2-NCP, Supplementary Material 1.2 and Díaz *et al.* (2018) for further description, examples and references concerning the 18 categories. Most NCP straddle across groups to some degree. To indicate this, the NCP in the material and non-material groups extend into their respective columns. The non-material dimension of regulating NCP is not necessarily as widely recognized across cultures; therefore, they are represented as encroaching only slightly beyond their column in the Figure. Maintenance of options (NCP 18), conveys the various dimensions of the potential opportunities offered by nature, and thus spans all three NCP groups.

most comprehensive available, would not be sufficient for the task at hand. The adoption by IPBES of a pluralistic and inclusive framework with its associated language including concepts such as nature, nature's contributions to people and quality of life was necessary on three grounds: fuller and more symmetric consideration of diverse stakeholders and worldviews, a richer evidence base to inform action, a broader inclusion of contemporary categories and questions of the social sciences and humanities. We elaborate on these three aspects below.

First, there are increasing calls for considering issues of *legitimacy, fairness, social equity* (Görg *et al.*, 2016; Pascual *et al.*, 2014) and rights (including human rights to the environment and to cultural identity; Knox, 2017) in environmental science-policy interfaces (CBD, 2010; ISSC *et al.*, 2016), and this is reflected in the mandate of IPBES. This new emphasis is partly due to a recognition that environmental decision-making has in the past often benefited majority populations (e.g., urban, wealthy, ethnic majority) with limited or negative outcomes for minority populations (e.g., rural, poor, minority groups). This can in turn have negative implications for environmental management itself, as poor, rural, indigenous or local populations are generally key actors in environmental management or deterioration. The implications of context such as gender have also been demonstrated to be of critical importance in environmental outcomes (Keane *et al.*, 2016). From the beginning, it became clear that the CF had to represent diverse views. For example, participants in the process rejected the notion that "ecosystem services", at least in its most widespread versions, effectively represented all ways of understanding the diverse contributions that nature makes to human quality of life. It was necessary to use a different term, with less baggage in any particular intellectual tradition (Castree, 2013; Rey, 1983), and with immediate meaning to as many people as possible. That different and broader term became "nature's contributions to people", with the assumption that it encompassed all the diverse and interesting research on ecosystem services, as well as other views and sources of evidence (Díaz *et al.*, 2015a, 2015b, 2018). By creating this intellectual space, IPBES does not compromise intellectual rigor; rather it recognizes the legitimacy and relevance of other views in understanding what nature can do for and with us. Therefore, through its explicit recognition of different worldviews and epistemic categories, the CF framing, including NCP, facilitates the practical incorporation of these considerations in the assessment process, and fosters broader ownership and adoption of its results across disciplinary, regional and cultural contexts. Regarding the use of terminology, the CF provides a more neutral way to refer to our links with the non-human living world in which we are inextricably linked as part of the fabric of life on Earth. We use 'people' to denote that we inclusively refer to all genders, ages, social groups (be them based on citizenship, ethnicity, class or occupation). In the broader community (i.e., beyond IPBES), different stakeholders will refer to e.g., women, children, clients, patients, particular ethnic groups, workers, entrepreneurs, etc.

Similarly, we use 'nature' to denote all non-human living entities and their interaction with other living or non-living physical entities and processes. Nature embodies different concepts for different people, including biodiversity, ecosystems, Mother Earth, Country, se¯nluo´-wa`nxia`ng and other analogous concepts (see **Box 1.2**). We use 'quality of life' to denote the vision and the achievement of a fulfilled human life. Different stakeholders will refer specifically to e.g., income, satisfaction, human development, happiness, sense of identity, vida plena, buen vivir (see **Box 1.2**). Finally, we use 'NCP' to denote all the beneficial and detrimental contributions that we obtain from and with nature. Different stakeholders, according to their goals, needs, motivations and preferences, will use other terminology such as goods, ecosystem services, gifts from nature, living natural resources, products, experiences, environmental endowments, among many others (see **Box 1.2** and Section 1.3.1.1).

Second, the IPBES CF, including the NCP concept, *expands the conceptual, methodological and empirical evidence base* from which assessments can produce options for action, and provides important opportunities for the evolution of research. The construction of the new

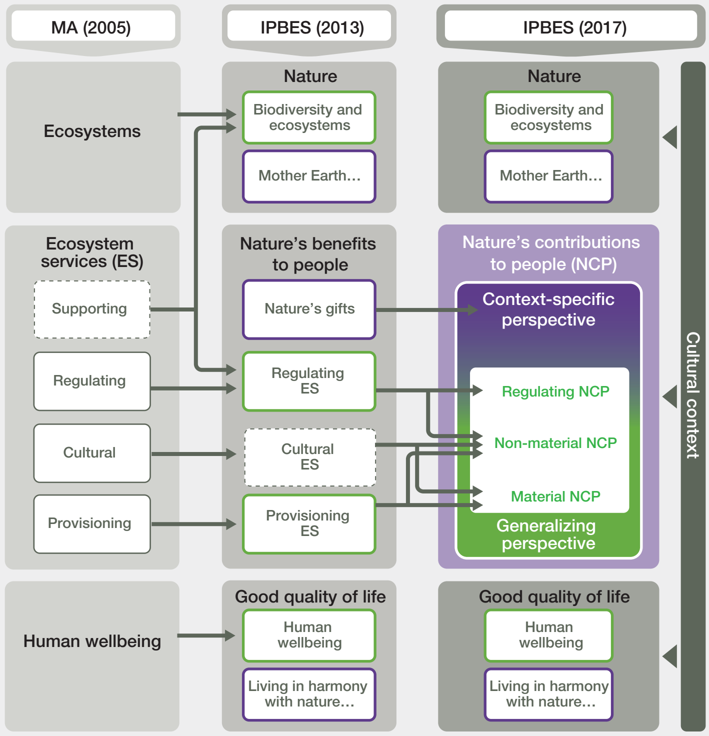

Figure 1 4 **Evolution of nature's contributions to people (NCP) and other major categories in the IPBES CF (Díaz *et al.*, 2018) with respect to the concepts of ecosystem services and human wellbeing as defined in the Millennium Ecosystem Assessment (2003, 2005).**

The element "nature's benefit to people" was adopted by IPBES Second Plenary, and further developed into NCP by the fifth session of the Platform's Plenary (IPBES-5) (Decision IPBES-5/1) in order to fully capture the fact that the concept includes all contributions to people, both positive (benefits) and negative (detriments). Concepts pointed by arrow heads replace or include concepts near arrow tails. Concepts in dotted-line boxes are no longer used: following the present view of the MA community (Carpenter *et al.*, 2009; Reid & Mooney, 2016), supporting ecosystem services are now components of nature or (to a lesser extent) regulating NCP. Cultural ecosystem services was defined as a separate ecosystem service category in the MA; IPBES instead recognizes that culture mediates the relationship between people and all NCP. For more details of NCP according to the generalizing and conceptual perspectives, see **Figure 1.3**.

framework **(Figure 1.2)** was informed by the increasing number of papers and assessments in the ecosystem service and conservation literature that had been striving to accommodate values and metrics beyond those of ecology and economics, and opened to the call from social and political sciences and humanities working from outside those paradigms to incorporate their concepts and questions and not just their data (Castree *et al.*, 2014; Nadasdy, 2011; Olsson *et al.*, 2015). In full recognition of all these intellectual streams that inspired it, the IPBES CF, including the NCP approach, strives to formalize and strengthen them in a cohesive structure suitable for operation in the science-policy interface. This additional input can have direct practical positive implications for science and policy: for example, ILK can serve to address issues of uncertainty in ecosystem management, through processes that have been honed at local levels from generations of feedback learning (Berkes *et al.*, 2000). Furthermore, it allows a more appropriate representation of concepts within and between categories of nature´s contributions or ecosystem services, building upon developments produced during the past decade, many of them within the evolving context of ecosystem service research. Prominently, it adopts the representation of culture as a crucial lens by which we understand nature and its effects, rather than as a category of service (Chan *et al.*, 2012b; Fish, 2011; Pröpper & Haupts, 2014). It takes into account critiques to the natural capital stock-and-flow model from conservation and evolutionary ecology, stressing the value of nature beyond flows and economic production functions (e.g., Faith, 2018; Silvertown, 2015). It also recognizes that people may perceive and value the contributions from nature in diverse ways, including different classes or bundles at group or individual levels (Klain *et al.*, 2014; Martín-López *et al.*, 2012; Milcu *et al.*, 2013). Non-material and material benefits from nature are often intimately intertwined, not separate categories for separate things (Chan *et al.*, 2012a; Klain & Chan, 2012; Turner *et al.*, 2008).

Finally, the IPBES CF, including the notion of NCP, allows *a broader inclusion of the categories and questions of the social sciences and humanities*. The insights above were largely derived from fields of social sciences and humanities that received scant inclusion within dominant ecosystem service framings (Daniel *et al.*, 2012; Stenseke & Larigauderie, 2017), even though these insights did percolate to some degree into the ecosystem services literature. This includes long-term acknowledged insights that human and societal interactions with nature are complex, articulated through emotions and practices, and, moreover, that human-environment relations are dynamic as social structures and physical conditions change over time (Castree, 2017; Macnaghten & Urry, 1998; Setten *et al.*, 2012). This is not restricted to ILK systems. Qualitative approaches in humanistic and social science point to a less linear understanding of human societies and social change, beyond what a systems perspective can account for (Harris, 2007; Setten *et al.*, 2012; Shove, 2010), thus requiring full attention to different cultural perspectives and value systems.

By building the above insights into the structure of the NCP approach, the hope is that NCP might better include diverse perspectives (Díaz *et al.*, 2018). Furthermore, it may help avoid the problematic simplification of relationships with nature (Faith, 2018; Norgaard, 2010; Turnhout *et al.*, 2014) and appeal to a more diverse set of social scholars, given relatively widespread reservations about ecosystem services (Dempsey & Robertson, 2012; Droste *et al.*, 2018; Satterfield *et al.*, 2013; Satz *et al.*, 2013).

In summary, like any transition in concepts and terminology and any meeting of frameworks, the challenges – conceptual, epistemological, methodological, even ontological– are formidable. Also like in any transition, there is contestation, coexistence and cross-fertilization with previous framings. For example, the ecosystem service framework, after it was created and became widespread by its adoption by the MA, coexisted for a long time, and still coexists, with the framework of renewable natural resources. Because of its flexibility, the CF framing does not require drastic re-framing of existing initiatives, organizations or research programs that do not feel the need to change, although many could easily transition to it and benefit from a wider "conversation". In other words, the concept of NCP, together with a flexible reporting system, helps IPBES to meet the requirements for successful knowledge mobilization for sustainability: legitimacy, salience, credibility and usability (Clark *et al.*, 2016; Fazey *et al.*, 2014).

1.3.1.3 Diverse conceptualization of the multiple values of nature and its contributions to people

Understanding values and their diversity, how they are conceptualized and formed and how they change over time and across contexts and scales, is critical to the understanding of human-nature relationships, and thus to inform decision-making and policy design. The ways in which nature and its contributions to people for a good quality of life are perceived and valued may be starkly different between regions, societies and sectors within societies (Martínez-Alier, 2002). Multiple values can be associated with multiple cultural and institutional contexts – different agents may assign very different values to the same object, contest the values of others, and justify their actions on the basis of such differences. Value conflicts may emerge due to uneven power relations because those with more power see their values enacted, while those with less power see their values ignored in practice (Arias-Arévalo *et al.*, 2018; Berbés-Blázquez *et al.*, 2016). Ignoring different types of values associated with material, non-material, and regulating contributions of nature and thus not incorporating them in economic decisions is considered among the most significant factors underlying the loss of nature and its contributions to people (Duraiappah *et al.*, 2014; Kumar, 2010).

The global assessment recognizes that the word 'value' is always defined in the context of a given worldview and cultural context and can refer to a preference someone has for a particular state of the world, the importance of something for itself or for others, or simply a measure (IPBES, 2015; Pascual *et al.*, 2017). Acknowledging the need for a pluralistic approach towards the values of nature and its contributions to people is necessary but not sufficient to better inform policy options intended to transform society's relationship to nature in order to achieve common societal objectives such as those expressed in the Sustainable Development Goals and the Aichi Biodiversity Targets. Given the unequal capacity by different actors to express and support their own values regarding nature in the context of decision-making, it is important for policy to capture the diversity of values and find ways to reconcile them.

Furthermore, valuation of nature and its contributions is based on a specific set of ethics and normative positions determining what value system is seen as culturally appropriate and thus applied. Such normative positions in valuation may be starkly different and even conflicting between regions, societies and sectors within societies. In general, the valuation of natural resources, ecosystem services and –more recently– NCP has tended to rely on a unidimensional-value approach, where a dominant view over nature prevails in decision-making. Most often, such views clash, as they tend to either derive from a utilitarian economic perspective, or a biocentric stance that imparts intrinsic values to species and nature. The global assessment acknowledges the influence of both value lenses and the conflicts that may arise when decision-making trumps one perspective over another; it also supports an inclusive valuation perspective consistent with the IPBES CF (Pascual *et al.*, 2017). This is important as the ways in which values are assessed carries wide implications for the analysis of trade-offs of benefits and detriments to different people, for nature, and for the future of both. For instance, when a resource is extracted from nature, embedded are the land and water inputs, the carbon emitted, the pollution produced, the biodiversity affected, the limitations on other users as well as the aesthetic beauty that some appreciate, the sacred value embedded in place, and the social relations directly or indirectly linked to such resource.

As depicted in **Figure 1.5**, the analytical framework used in the global assessment places types of values along a gradient of anthropocentric to non-anthropocentric values, including instrumental, relational, and intrinsic values, on nature, nature's contributions to people and a good quality of life (Pascual *et al.*, 2017). The colour gradient indicates that both instrumental and relational values (anthropocentric values) can be ascribed to nature's contribution to people, and highlights examples of sources of value based on what people may seek in the pursuit of a good quality of life through interaction with nature; it also explicitly includes perceived intrinsic worth (non-anthropocentric value).

The three major types of values considered in IPBES are:

- **Intrinsic values** refers to the value of an entity (e.g., an organism, an ecological process) independent of how it relates to humans.

- **Instrumental values** are associated with an entity that serves to achieve a human end, interest or preference. Instrumental value includes economic values, regardless whether the entity is directly or indirectly used, or not used (existence and bequest values).

- **Relational values** are associated to the meaningfulness of relationships, including the relationships among humans and nature and among humans, including across generations, via nature (Chan *et al.*, 2016). These values are attached to the entity itself in ways that make it not substitutable, hence not serving an instrumental or utilitarian perspective (O'Neill, 2017), and represent what people consider meaningful about nature (e.g., attachment, responsibility, commitment). Relational values can also be associated with relationships with nature towards achieving a good life, e.g., when choosing "the right thing to do" or in the context of a "meaningful life." (Pascual *et al.*, 2017).

While all types of values are considered to some degree in the global assessment, the chapters examine instrumental

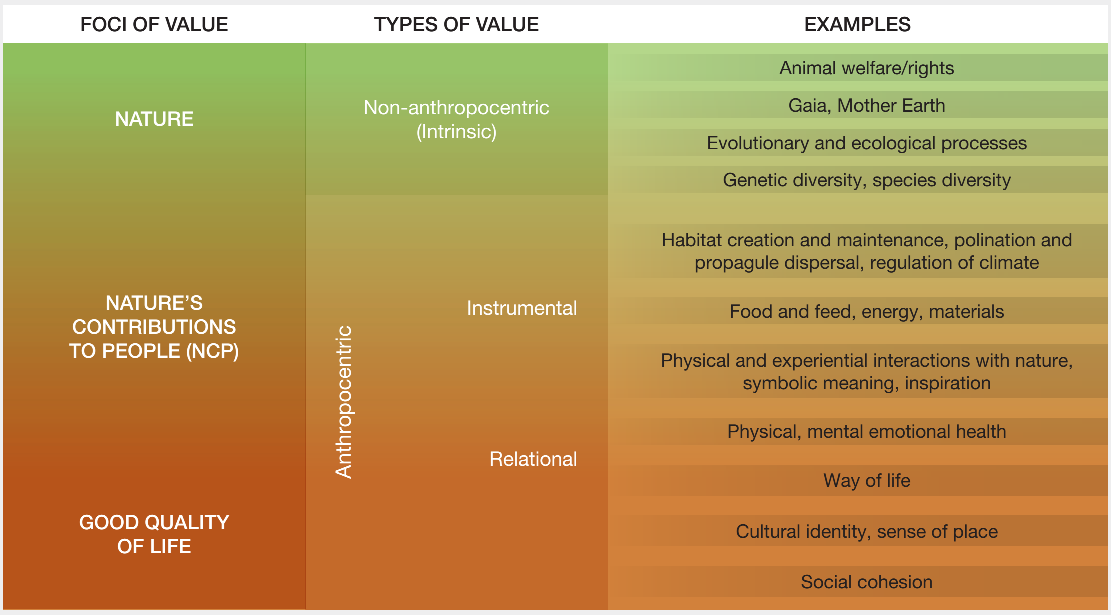

Figure 1 5 **Diverse values related to nature, nature's contributions to people (NCP) and a good quality of life (GQL), following Pascual *et al.* (2017).**

The grading in the colors indicate that both instrumental and relational values can be ascribed to the value of nature's contributions to people, and to highlight that nature's contributions to people are intertwined with nature and a good quality of life.

and relational values in much more detail. The analyses presented in Chapters 2 to 6 take into account, to various degrees, how diverse types of values underlie societies' relationships with nature, the appropriation of NCP to support a good quality of life, and the ways in which values are embedded in, and can be transformed by policy instruments and collective action.

1.3.1.4 Good quality of life – its links with nature and nature's contributions to people

Numerous conceptualizations of quality of life have been proposed over the years (Stiglitz *et al.*, 2009), combining different notions of basic human needs (Maslow, 1943; Max-Neef, 1991), freedoms and capabilities (Nussbaum, 2000; Sen, 1999), or opportunities (Costanza *et al.*, 2007). The Millennium Ecosystem Assessment (2005) represented a significant advance in recognizing multidimensional aspects of well-being and their relationships to different types of ecosystem services. The IPBES CF builds upon these efforts, recognizing that human quality of life is multidimensional, including objective and subjective dimensions, all of which pose challenges to measurement and interpretation.

Recognizing that human quality of life is a context-dependent state of individuals and human groups, the CF includes the inclusive notion of Good Quality of Life (GQL), understood as the achievement of a fulfilled human life, including material and non-material dimensions (Díaz *et al.*, 2015a). Under the umbrella of GQL, multiple concepts and terminologies may be used to reflect different sociocultural perspectives or assessment goals. For example, this includes, the concept of human well-being, which is widely used in national policy and international development reports includes subjective cultural values and personal aspirations (livelihoods, happiness, vulnerability, freedom of choice, security, etc.), relationships (social relations, action and participation in society, etc.) and access to resources (food, water, energy, shelter). It is often reported through synthetic indicators such as the 'human development index' (HDI) that build on standardized per capita income as well as other indicators such as based on education, child mortality, and life expectancy, although it does not include considerations to environmental and subjective aspects of human well-being (see **Box 1.2** for more details).

The global assessment intends to be inclusive in its approach to assess nature's contributions to a good quality of life, including not only different notions of what a good life entails, but also its linkages to patterns of inequality associated with changes in nature. **Table 1.1** presents a list of 14 categories of material and non-material indicators intended to capture the various aspects of GQL. These categories build upon and expand the categories used in the Millennium Ecosystem Assessment (2005), and are used throughout the present assessment, such as to discuss the implications of specific aspects of NCP, indicators of progress in societal goals (e.g., Aichi Biodiversity Targets, SDGs), implications of future scenarios to GQL, and the situation of IPLCs relative to other groups.

1.3.1.5 Institutions in the IPBES Conceptual Framework

The global assessment follows the widely accepted definition of institutions, understood as formal and informal rules and norms that structure individual and collective behaviour (Ostrom, 1990, 2005). In other words, institutions are collectively produced by actors and in turn shape their behaviour, stimulating, directing or restricting action (Giddens, 1986). The IPBES conceptual framework places institutions at the centre of our relationship to nature and biodiversity. This approach has helped to fill gaps in previous assessments, where the role of institutions at different societal levels was not elaborated. Institutions are the expression of the plurality of individual and collective practices underlying human individual and social behaviour towards each other and towards biodiversity and nature. Institutional arrangements act upon and mediate processes of natural resources claim and uses, and therefore the management of nature and biodiversity.

A variety of formal and informal institutional arrangements mediate interactions between our demand for a good quality of life and the pressures it puts on nature and biodiversity, and thus nature's contributions to people. Institutions as politically relevant social rules and norms can be thought of in terms of institutional orientations (e.g., social narratives, social expectations and behavioural norms, as well as social hierarchies and ascribed status), and allocative and distributive mechanisms (e.g., property systems and access rights to common and public goods, markets, formal and customary laws, policies including taxes, subsidies). Institutions are not equivalent to organizations, however the latter are composed of multiple institutions representing systems of rules and norms, for instance ministries, political parties, advisory boards, corporations, among others. Institutions also underlie, *inter alia*, investment initiatives and multilateral environmental and trade agreements, as well as their effects on other components of the conceptual framework.

As institutions emerge from interactions between people and social structures, they influence how decisions are taken and implemented, how power is exercised, and how responsibilities are distributed. Institutions determine to various degrees the access to, allocation and distribution of the various forms of resources and the benefits we derive from them. They can be organized along a

Table 1 1 **Material and non-material dimensions of a good quality of life (GQL) used across chapters of the global assessment.**

Adapted from the Millennium Ecosystem Assessment (2005).

GOOD QUALITY OF LIFE	DESCRIPTION
MATERIAL dimensions	
Food security	Involving components of knowledge, availability, access, utilization, stability, diversity and cultural preference
Water security	Involves quality, sufficiency, and access
Energy security	Involves availability, access and affordability without incurring health and physical risks
Shelter	Ability to live in a clean and safe shelter, reduce risk and vulnerability to hazards and stochastic events
Livelihood and income security	Ability to access resources, income necessary to fulfil material needs and social obligations, and pursue education, health, leisure, and work opportunities
Health	Including being nourished and functional, free of diseases, psychological satisfaction
NON-MATERIAL dimensions	
Good Social relationships	Including social cohesion, mutual respect, good gender and family relations, the ability to help others and provide for children, and the opportunity for active participation in one's society
Equity	Concerns evidence of parity in processes and outcomes across gender, age, race and ethnicity, income and other social indicators or dimensions of difference
Sense of cultural identity	Feeling of belonging to one or more social groups (as related for instance to locality, country, ethnicity, religion, activity, gender, generation), being respected for self-determination, practice of language, education and transmission, and ability to carry out activities related to intangible values and culturally valued means of existence
Personal and physical security	Including secure access to natural and other resources, safety of person and possessions, and socially equitable access to supporting systems and living conditions to be resilient to natural and human-caused disasters
Freedom of choice and action	Including having control over what happens and being able to achieve what a person values doing or being
Access to knowledge and education	Ability to pursue formal and informal education and knowledge in culturally appropriate languages, learning new skills, and accessing information necessary for participation in society and pursuit of culturally valued aspirations
Freedom to exercise spirituality	Ability to exercise one's faith, beliefs, and religious practices
Access to recreation and leisure	Ability to dedicate time to physical and psychological health, to have access to socially valued activities and spend time with family and friends
Enjoyment of natural beauty	Capacity to enjoy the beauty of nature, healthy and unpolluted landscapes and seascapes, also reflecting one's sense of place, artistic and spiritual inspiration, physical and emotional comfort

continuum of temporal and geographical scales spanning from the organizations of local groups and resource users to national governments to global institutions, such as in international treaties and policies or an intergovernmental platform such as IPBES. Also, at the global level, an international climate agreement for instance is an example of an institution that has both formal aspects (e.g., agreed emissions quotas) and informal aspects (e.g., a country's moral pledge). At all levels, institutions are expressed in the policies, property systems, the organization of markets, and the formal and informal agreements that create incentives and/or restrictions on our behaviours and attitudes towards nature. Institutions are thus behind the ways we monitor, control, reward and sanction behaviours, including defaulting to no action at all, e.g., the absence of a norm or rule regulating the use of a resource represents itself a mode of action.

The global assessment examines a plurality of institutional arrangements that have emerged within different contexts over the past 50 years to promote the sustainable management of nature and biodiversity and to address global problems such as climate change (Young, 2010). From local to global levels, chapters examine the ways institutions, for instance those related to conservation, are challenged by competing values and power dynamics, changing contexts and environmental conditions, its congruency with other institutions operating at intersecting social and ecological boundaries.

Consideration of formal and informal institutions in the global assessment is done in various ways depending on the focus of analysis, including how the respective institutions create and mediate particular drivers of change, their potential effectiveness or lack thereof in reducing the impact of drivers on nature and people, their short and long-term effectiveness in reaching goals in a cost effective and, not least, equitable manner, i.e., their effects on distribution of benefits and costs across individuals and groups within society. Another important aspect considered in institutional analyses in the global assessment relates to understanding how institutional arrangements interact, support and/or contract each other, and match or mismatch to ecosystem boundaries at different scales (Bodin, 2017; Brondizio *et al.*, 2009). Understanding the mismatches between institutional arrangements and ecosystems is particularly critical to understand social-ecological changes at regional and global scales. At these levels, common pool resource systems, such as a water, climate and atmosphere, the oceans, migratory species and other resources exhibit inherently emergent and transboundary properties, affected both by level-specific and cross-level institutions and decision-making, including distant drivers of change.

1.3.1.6 Direct and indirect drivers of change and their telecouplings

Within the global assessment we differentiate between indirect drivers (all anthropogenic in our framework), and direct divers (natural, anthropogenic, and natural-anthropogenic-interaction), and how they interact **(Box 1.2)**. Decisions such as macroeconomic policies implemented through formal institutions may not be the direct cause of a change in an ecological system but may have a direct influence on the direction and intensity of direct drivers of change such as land use, pollution, direct exploitation, and different manifestations of climate change. In turn, formal and informal institutions also mediate these interactions. The difference between direct and indirect drivers have important implication for policy considerations, i.e., while a direct driver can be addressed through more focused efforts and instruments, addressing indirect drivers may require more fundamental and systemic change.

Building upon previous efforts and typologies of drivers of change, the global assessment analyses drivers in two main ways: the analysis of direct and indirect drivers, and the analysis of their distant interactions, i.e., telecoupling. The first way in which drivers are analysed in this assessment is by the use of a common typology, applied consistently across chapters, although some variation in terminology is inevitable as the literature on the topic is diverse and continues to evolve (**Table 1.2**; Supplementary Material 1.3). Direct drivers have direct physical (e.g., mechanical, chemical, noise, light) impacts on nature and/or people. They are also sometimes referred to as 'pressures' (e.g., CBD, 2014; MA 2005) or 'proximate sources' (e.g., Lambin *et al.*, 1999, 2006; Turner *et al.*, 1990, in the literature in the context of other initiatives. According to the typology adopted by the global assessment, direct drivers include, *inter alia*, natural drivers such as eruptions and earthquakes, anthropogenic drivers such as pollution, land/sea use change, and direct exploitation and extraction of resources, and drivers that are derived from natural-anthropogenic interactions, such as different manifestations of climate change and invasive alien species (including zoonoses). Indirect drivers are drivers that operate diffusely by altering and influencing direct drivers. They do not impact nature directly, rather, they do it by affecting the level, direction, rate, and/or intensity of direct drivers. They have been referred to as 'underlying causes' or underlying 'driving forces' in the context of other initiatives (e.g., Lambin *et al.*, 1999; Maxim *et al.*, 2009). Both direct and indirect drivers can also affect other indirect drivers through different chains of relationship, varying in type, intensity, duration, and distance. These relationships can also lead to different types of spill-over effects (Liu *et al.*, 2013). Indirect drivers include institutions, economic, demographic, technological, governance, regional conflicts and wars, sociocultural and socio-psychological, and health related drivers. As discussed above, attention is given, among indirect drivers, to the role of institutions (both formal and informal) and impacts of the patterns of production, supply and consumption on nature, nature's contributions to people and to quality of life. Also, in the scenarios chapters (4 and 5), indirect drivers play an important role within the causal linkages to biodiversity and ecosystem change (IPBES, 2016b). Many global environmental scenarios are constructed on the basis of assumptions related to the development of these indirect drivers according to different storylines. Commonly, scenarios include indirect drivers such as model of economic development, demographic trends and factors, technological development, governance and institutions, and socio-cultural context. These analyses are developed on the basis of assumptions about how indirect drivers interact with current trends, providing the qualitative and (semi-) quantitative basis for models on the implications of direct drivers for nature, its contributions to people and to quality of life.

Drivers can be analysed from the perspective of distant influences and interdependencies, usually referred to as teleconnections and telecoupling, respectively (Friis *et al.*, 2016; Liu *et al.*, 2013, 2015). In the global assessment, the concept of 'telecoupling' is used to emphasize that human-nature interactions are interconnected through different chains of relationships, attributions, and impacts which may influence each other, varying according to type, intensity, duration, and distance of the interaction, and often exhibiting nonlinear patterns over space and time. Thus, telecoupling is used in the assessment as an umbrella concept encompassing processes that are distant not only

Table 1 2 **Typology of drivers used in the IPBES Global Assessment.**
See Supplementary Material 1.3 for a more detailed description.

DIRECT DRIVERS	**Natural**	Eruptions, earthquakes, natural climatic variability		
	Anthropogenic	Pollution (emissions, disposal, spill-overs, noise, others)		
		Land/sea use change	Transformations	
			Intensity changes	
		Direct disturbance, exploitation and extraction (of components of nature)		
	Natural-Anthropogenic (interaction)	Manifestation of climate change (e.g., changing temperature and precipitation, frequency and intensity of weather events, sea level change, ocean acidification)		
		Invasive alien species including zoonoses and pest outbreaks		
INDIRECT DRIVERS		Institutions (formal and informal)		
		Economic drivers	Patterns of supply	
			Patterns of production	
			Patterns of consumption	Economic affluence
				Inequality
				Poverty
		Demographic drivers		
		Technological drivers		
		Governance drivers		
		Conflicts and wars		
		Sociocultural and socio-psychological drivers (values, beliefs, norms, education)		
		Health problems as indirect drivers		

spatially but also in the temporal and functional senses. The term applies to a range of relevant phenomena related to nature, NCP and GQL, such as food trade impacts (Chaudhary & Kastner, 2016; Easter *et al.*, 2018; Sun *et al.*, 2017), food security (Nelson *et al.*, 2016), large-scale land acquisition (e.g., land-grabbing) (Rulli *et al.*, 2013), freshwater demand, and a variety of resource trades (Xiong *et al.*, 2018). Telecoupling approaches have been used to examine the relationship between resource demands and declines in biodiversity and ecosystem services, competition for water, the impact of tourism, processes of species invasion, the impact of foreign investment on the environment, the spread of diseases and connectivity of ecosystems, among others. In different parts of the assessment, authors use the perspective of telecoupling to examine ecological, physical, climatic and other natural telecouplings, as well as economic telecoupling such as trade and investments, sociocultural telecoupling such as in the circulation of expressive culture, symbols and narratives, and legal telecoupling, such as related to the impact of domestic regulations or international agreements on far-away areas and stakeholders. Global input-output (IO) analysis is used to quantify and qualify the economic interdependencies, such as to assess the trade and supply chains that connect primary producers and final consumers, often geographically far removed from each other.

1.3.2 Incorporating Indigenous and Local Knowledge and issues concerning Indigenous Peoples and Local Communities: a systematic and multi-facet approach

1.3.2.1 Defining and conceptualizing Indigenous Peoples and Local Communities, and Indigenous and Local Knowledge

Indigenous Peoples and Local Communities (IPLCs) is a term used internationally by representatives, organizations, and conventions to refer to individuals and communities who are, on the one hand, self-identified as indigenous and, on the other hand, are members of local communities that maintain inter-generational connection to place and nature through livelihood, cultural identity and worldviews, institutions and ecological knowledge. The term, as other similar regional terms, has gained usage in international forums during the past 2 decades. The term is not intended to ignore differences and diversity within and among Indigenous Peoples and between them and local communities. It is used largely to denote that there are communalities and shared concerns for Indigenous Peoples and Local Communities that are important to be represented in international forums, such as the CBD, IPCC, IPBES, among many others.

Indigenous and Local Knowledge (ILK) is a closely related term also widely used internationally and in published literature to refer to the worldviews, knowledge, practices, and innovations embedded in the relationship between people and nature, as expressed in local knowledge about the natural world, techniques and technologies of resource management, as well as in local institutions governing social relations and relationship to nature. Equivalent terms include Traditional Ecological Knowledge and Local Ecological Knowledge, among several others. ILK is understood as situated in place and social context, holistic but at the same time open and hybrid, continuously evolving through the combination of written, oral, tacit, practical, and scientific knowledge attained from various sources, validated by experimentation and in practice of direct interaction with nature. As IPLCs are confronting pressures and undergoing sociodemographic, cultural, economic changes worldwide, inter-generational transmission of ILK is declining fast in many regions of the world (e.g., Turnbull, 2009).

Both terms, IPLCs and ILK, are used as umbrella terms to represent the most culturally diverse segment of the world's population, which in spite of such diversity, share many common concerns (see section 1.3.2.2). The global diversity of IPLCs –cultural and historical, social and political, economic and environmental– defy a common definition for the term as a whole and for each of its two components. While the United Nations has recognized and used multiple criteria to define 'Indigenous Peoples', including ancestry, distinct cultural features such as language, religion, membership in tribal systems, material culture, cosmology, livelihood, origin and residence, among others, no common definition has been adopted internationally. Instead, the United Nations, as many countries, have increasingly adopted self-identification, by individuals and their acceptance by a community, as a primary criterion. Likewise, no single definition of 'local communities' is internationally accepted. In the CBD, as other international platforms such as IPBES and IPCC, local communities are recognized for their diversity, yet having historical linkages to place and natural resources, their multiple domains of ecological knowledge, dynamic and hybrid resource management techniques and technologies, their customary and formal institutions to manage natural resources, their diverse worldviews and forms of relationship to nature.

In the absence of a comprehensive general definition of IPLCs, authors of the global assessment were particularly concerned with recognizing intra- and inter-regional differences in definitions regarding IPLCs and ILK. Many Indigenous Peoples and Local Communities are not recognized as such, or at all, by their respective countries or in the literature. For historical, political and language reasons, some groups are highly visible and others invisible to policymakers, scholars, society, and even representatives of IPLCs. For these and other reasons, authors of the global assessment were sensitive to the fact that definitions of ILK and IPLCs are context-specific and should be recognized as such, and as inclusive as possible when evaluating data and literature. The operational strategy developed to include ILK and IPLCs in the assessment recognizes the criteria of self-identification and self-determination for IPLCs.

Table 1.3 shows 15 dimensions used as a reference to contextualize the diversity of IPLCs around the world. In practical terms, this meant maintaining literature review data disaggregated to allow different interpretations of whom to include as IPLCs and what as ILK. Likewise, as expressed in the questions guiding the work on ILK and IPLCs in the assessment (**Box 1.3** and Supplementary Material 1.4), we have placed a particular emphasis on the relationship between knowledge, practice, and innovations. As such, these guiding questions are intended to highlight that irrespective of cultural differences, importance was given to assessing the contributions of IPLCs to the stewardship and management of nature, and its contributions locally and to the larger society, without romanticizing ILK. Literature review and dialogue workshops also allowed authors to assess the pressures experienced by IPLCs in different parts of the world as well as relevant policy options and instruments concerning, directly or indirectly, IPLCs.

It is important to note that many groups of farmers, ranchers, pastoralists, fishers, and foresters who also have multi-generational roots in place, close connection to nature, and directly contribute to the management and conservation of biodiversity, may not be included, for multiple reasons, as belonging to the broader category of IPLCs. Independently, authors of the assessment have also used and included literature regarding the management and conservation practices found in regions around the world.

Estimates suggest that Indigenous Peoples (IP) include some 5000 groups, comprising between 300–370 million people (Hall & Patrinos, 2012), ranging from isolated groups to large populations across most regions of the planet, including in urban centres. Local Communities (LC) on

Table 1 3 **Recognizing the global diversity of Indigenous Peoples and Local Communities.**

DIMENSIONS	GRADIENT OF CONDITIONS		
1. Demography	Small population	⟷	Large population
2. Social identity	Unrecognized	⟷	Formal
3. Language	Endangered	⟷	Expanding
4. Environment relationship	Continuous, inter-dependent	⟷	Sporadic/aesthetic/specialized
5. Land/territorial security	Informal/contested	⟷	Formal/recognized
6. Economic relations	Self-sufficiency, reciprocity	⟷	Market, trade
7. Property system	Open, common	⟷	Private, dispossessed
8. Technology use	Local techniques	⟷	Conventional, energy-intensive
9. Knowledge base, transmission	Oral/culturally coded	⟷	Recorded
10. Urban relationships	Distant	⟷	Inter-dependent
11. Socio-economic conditions	Poverty	⟷	Security
12. Security, pressures	Low	⟷	High
13. External dependency	Self-sufficient	⟷	Aid-dependent
14. Existence and Persistence	Millennia	⟷	Decades to centuries
15. Degree of self-governance	Autonomy and sovereign rights	⟷	External control

the other hand involve an even larger, and equally diverse population ranging from communities in peri-urban and coastal zones to rural communities isolated from urban centres inhabiting sparsely populated landscapes, coastal areas, and small towns around the world (see **Box 1.4**). While representing large sectors of the rural population in developing countries, they also represent important segments of the population in developed countries, producing diverse food and products, managing cultural and production landscapes, safeguarding agrobiodiversity and the genetic diversity of domesticated animals, and carrying the know-how of material culture and technology, food cultures and medicines and associated intangible heritage. As the application of the term may vary according to national or regional context, there are no clear ways to estimate the world population that could be classified as local communities. Proxy estimates based on factors such as distribution of smallholders in rural areas and land managed under customary rights would suggest a population around well above 1 billion people **(Box 1.4)**. They include micro-, small- and medium-scale farmers, herders and pastoralists, fishers, extractors and foragers, foresters and agroforesters managing a significant portion of the world's terrestrial and coastal landscapes and biodiversity.

In some regions, the IPLCs experience marginalized socioeconomic conditions. Many IPLCs share conditions of poverty, experience violence, have limited access rights to land and resource, and lack of access to conventional and to culturally sensitive health care systems. They also lack access to education appropriate to local culture, as well as public services such as water, energy, and sanitation (Ding *et al.*, 2016; Hall & Patrinos, 2012; Pearce, 2016; Romanelli *et al.*, 2015). Throughout the world, the IPLCs experience contestation of customary rights, physical and legal conflicts with mining companies, large-scale agriculture, forest companies, multinational oil corporations, as well as displacement associated with these pressures, from migration to government development programs. On the other hand, as the chapters of the assessment show, a multitude of examples exist of IPLCs leading innovation and collaborative efforts to manage and conserve nature, implement sustainable management practices, and find solutions to local problems.

Box 1 3 Global estimation of lands held and/or managed by Indigenous Peoples and Local Communities and 'counter-mapping' efforts.

The lands held in rights and/or managed by Indigenous Peoples and Local Communities (IPLCs) are found in all inhabited regions of the world (Dubertret & Alden Wily, 2015). It is estimated that between half and two-thirds of the world's lands are under customary tenure or community-based regimes, mostly held by IPLCs (Alden Wily, 2011). Estimates suggest that customary tenure, a significant portion of which overlap with different types of government, corporate, and/or private control, may extend to over 8.54 billion hectares or around 65% of the global land area inhabited by around 1.5 billion people (Alden Wily, 2011). Among them, between 300 and 370 million self-identify as Indigenous Peoples, who currently inhabit and manage around 28% of the global land area (Nakashima *et al.*, 2012; Garnett *et al.*, 2018). Pastoralists and agropastoralists, estimated to represent around 120 million people at the global level, move over larger areas and across altitudes within and beyond borders and across land held in different types of customary rights, often following pathways with long histories of transhumance (Rass, 2006). Still, only 10% of the world's land are formally recognized as indigenous and/or community lands (Rights and Resources Initiative, 2015). There are no global estimates available for the customary rights of IPLCs in freshwater and marine systems.

While representing the most up-to-date evaluation of IPLC lands globally, these estimates are limited by both the lack of visibility of IPLC lands in many regions and limited data. About 70% of land properties in low-incoming countries are unregistered (McDermott *et al.*, 2015), and 90% of Africa's rural land is estimated to be not formally documented (Byamugisha, 2013). Even when land titles have been issued to communities, relevant data and statistics regarding them may not be produced, such as in Peru where IPLC lands are not included in the official cadastral records, although communities have legal ownership rights over a third of the country's land area (IBC, 2016). However, decades of "counter-mapping" are progressively contributing to fill this lack of information: an ever-increasing number of maps are produced by and for IPLCs in all parts of the world, often used as means to depict the lands and resources they hold and use for asserting their customary land rights (e.g., Peluso, 1995). Local, national, or regional geographic platforms giving visibility to these maps multiply quickly[6]. For instance, the LandMark initiative (LandMark, 2018), has been scaling up these efforts by providing a global picture of IPLC lands, but, although more than a million maps covering 11.2% of the world's land have already been gathered on the platform, it is still far from complete. The existing geographic information on the matter is often scattered in many communities and organizations, some may see more harm than good in publishing politically sensitive IPLC land claims, and a large part of the world's IPLC lands are yet to be mapped. In another effort, using published open access data sources, Garnett *et al.* (2018) aggregated maps of indigenous lands for 87 countries. Another example is the Indigenous and Community Conserved Areas registry (ICCA Registry) has been instituted since 2009 through UN institutions, IUCN, the ICCA Consortium and additional partners to appropriately recognize the conservation and livelihoods role of IPLCs. While much has to be done to clarify the cartography of IPLC lands, ongoing efforts to fill critical gaps in information on the location and extent of indigenous and community lands has gained an important momentum (Corrigan *et al.*, 2016). Geospatial data integration, satellite monitoring, participatory mapping and transparency of information are increasingly playing a role in strengthening the tenure security of indigenous and community lands (Di Gessa, 2008).

1.3.2.2 Scaling-up the analysis of contributions of Indigenous Peoples and Local Communities to biodiversity management, conservation, and regional economies

Recognition and documentation of indigenous and local ecological knowledge, practices, and innovations (ILK) of Indigenous Peoples and Local Communities (IPLCs) show that they date back millennia, always evolving in dynamic and adaptive ways. They have been recorded in oral history and accounts in written texts such as large non-conventional scholarly texts of medical systems (e.g., Chinese or ayurvedic medicines), diverse art forms, popular literature, and various types of reports (Motte-Florac *et al.*, 2012). Oral histories, storytelling, songs and poems, objects and artifacts continue to be powerful and as relevant today as forms of knowledge transmission. In 2015, for instance, Australian researchers showed that Aboriginal memory regarding coastal inundation in Australia could be traced to over 7000 years (Nunn & Reid, 2016).

Today, evidence shows that IPLCs have shaped the ecologies and resource economies of vast regions of the world, from managing forests, soil fertility, grasslands, mountains, watersheds, and coastal areas to the cultivation and nurturing of domesticated and wild species and the management of vast social-ecological production landscapes for humans and non-humans. Such knowledge forms the basis of traditional medicines and modern pharmacological compounds, the foundational genetic basis of local and global crops, domesticated animals and an array of microorganisms used for making

6. Among many examples, see http://tierrasindigenas.org/ for Paraguay, https://raisg.socioambiental.org/ for the Amazon, www.mappingforrights.org/ for the Congo Basin, etc.

bread, cheese, preserves, and beverages. Currently, IPLCs manage, under various property regimes, a high proportion of global terrestrial and biodiversity rich landscapes, and a significant portion of coastal areas, and transboundary watersheds. Land managed by Indigenous Peoples alone cover at least ~38 million km^2 in 87 countries on all inhabited continents. This represents over a quarter of the world's land surface and intersects about 40% of all terrestrial protected areas and ecologically intact landscapes (Garnett *et al.*, 2018).

While local in action, IPLC management of nature provides contributions to the larger society, in rural and urban areas alike, including the provisioning of food, fibers, material, and medicine to local and to export markets, and the management of agrobiodiversity of major regional and global crops. In many regions IPLC lands contribute to the conservation of watersheds that supply large regional populations. Increasingly, scientific research and reports recognize the central role played by IPLCs to advance climate change mitigation initiatives and for the implementation of CBD's Strategic Plan for Biodiversity 2011–2020 and the 2050 Vision. Similarly, there is a wide body of evidence documenting the impact of economic development and cultural/social change on IPLCs, impacts that have accelerated since the 1970s and continue to do so in many regions.

While evidence on these contributions and transformations is robust, it is still regionally dispersed and includes significant gaps at the global level. The global assessment builds on previous and ongoing efforts to contribute to bridge these gaps through knowledge syntheses and integration and systematic literature reviews, the use of available geospatial data, online and face-to-face consultations with IPLC representatives and experts on indigenous and local knowledge and issues. Bringing together representatives of and experts on indigenous and local knowledge and issues in dialogue workshops, and producing synthetic reports, has helped in particular to identify commonalities among IPLCs across regions, specifically related to drivers of changes affecting them. Likewise, synthesis and upscaling has been facilitated through the examination of common themes, such as agrobiodiversity, local indicators of environmental change, protected areas, climate change mitigation, among others; themes which are relevant from local to global levels.

The global assessment builds upon a long history of efforts. Since the 1950s, numerous international efforts have emerged to recognize the rights and the knowledge of Indigenous Peoples in particular, including the Indigenous and Tribal Populations Convention of 1957, first international convention for the protection of Indigenous Peoples, and put forward by the International Labour Organization (ILO). In the early 1980s, the United Nations Economic and Social Council (ECOSOC) created the Working Group on Indigenous Populations (WGIP) and in 2000 established the United Nations Permanent Forum on Indigenous Issues (UNPFII), a body which continues to grow in scope and influence (also referred as United Nations Permanent Forum on Indigenous Peoples – UNPFIP). By 1989, a landmark international convention, the Indigenous and Tribal Peoples Convention or ILO Convention 169, advanced the original 1957 ILO convention. Finally, in 2007, after two decades of negotiations, the United Nations adopted the Declaration on the Rights of Indigenous Peoples. In spite of representing major advances, these conventions and declarations have not been without contestation and controversies, including on the definition and recognition of Indigenous Peoples in different parts of the world.

Along with growing concerns on environmental deterioration and human rights, and interest in locally developed and alternative approaches to managing the environment since the 1980s, attention has expanded to include a wide range of local communities, including forest peoples, farmers, fishers, herders, pastoralists, diversely manifested around the world. In many regions of the world, Indigenous Peoples and Local Communities joined forces with scientists, artists, civil organizations, and policymakers to raise attention to the interlocked plight of IPLCs and environmental degradation, progressively recognizing the distinct contributions to the larger society, including to international agreements on biodiversity conservation, sustainable development, and climate change. This expanded attention to local communities was already captured in the establishment of the Convention of Biological Diversity (CBD) in 1992, in particular the provision under Article 8(j) pertaining to IPLCs. Along with the efforts mentioned above, the CBD article 8(j) represented a watershed moment for the recognition of the knowledge, practices, and concerns of IPLCs, one that continues to grow today[7]. As part of this process, IPLC networks have expanded and are becoming increasingly instrumental in linking local to global concerns and voices of IPLCs.

The systematic inclusion of ILK and issues concerning IPLCs in global-scale assessments have been limited or at best based on case studies; however, they have been central to advance both understanding and the participation of IPLCs in such efforts. For instance, in 1999 UNEP published "Cultural and Spiritual Values of Biodiversity" as a complementary contribution to the First Global Biodiversity Outlook (UNEP, 1999). The Millennium Ecosystem

7. Article 8(j) has been a catalyst for advancing understanding and action to 'respect, preserve and maintain the knowledge, innovations and practices of Indigenous Peoples and Local Communities relevant for the conservation of biological diversity and to promote their wider application with the approval of knowledge holders and to encourage equitable sharing of benefits arising out of the use of biological diversity.' (CBD Working Group on Article 8(j)). https://www.cbd.int/convention/wg8j.shtml. Accessed April 2, 2018.

Assessment, published in 2005, included sections dedicated to ILK and IPLCs, particularly within its chapters related to 'cultural ecosystem services'. A rich array of regional assessments and syntheses has been developed, while focusing on different themes and issues. For instance, the Arctic Biodiversity Assessment (CAFF, 2013) prepared by the working group Conservation of Arctic Flora and Fauna (CAFF) of the Artic Council examined issues related to Indigenous Peoples and biodiversity in the Arctic including oral histories and other types of evidence on traditional ecological knowledge[8] (TEK).

During the last 20 years, international agencies under the United Nations, the World Bank, Consortium of International Agricultural Research Centres (CGIAR) research centres, and numerous Non-Governmental Organizations have published regional and global reports on various issues of concern to IPLCs. In parallel to these efforts, academic and non-academic literature dedicated to ILK and to issues of concern to IPLCs have expanded exponentially, increasingly written with and by representatives of IPLCs. Of particular relevance in recent years were the efforts carried out by organizations representing IPLCs in the CBD and other forums. A notable example was the publication in 2016 of the report *Local Biodiversity Outlooks: Indigenous Peoples' and Local Communities' Contribution to the Implementation of the Strategic Plan for Biodiversity 2011–2020* (FPP *et al.*, 2016) developed by the Indigenous Network of the Convention on Biological Diversity. The coverage of IPLCs and ILK in reports of the Intergovernmental Panel on Climate Change (IPCC), while limited, has also been progressively increasing (Ford *et al.*, 2016).

The establishment of IPBES' first work programme in 2012 represented a landmark in institutionalizing the inclusion of ILK in global and regional level assessments. The approval of IPBES' culturally-inclusive conceptual framework and related analytical tools (such as on nature's contributions to people and multiple values of nature), provided the foundation to include ILK as part of the IPBES's assessments on pollination, land degradation and restoration, and the four regional assessments covering the Americas, Europe and Central Asia, Africa, and the Asia-Pacific region. These assessments also contributed to advance mechanisms for consultation with IPLC representatives, such as through the organization of dialogue workshops incorporated as part of the assessment process. From the onset, IPBES formed a Task Force on ILK dedicated to developing guidelines for integrating ILK in IPBES activities. This task force is currently involved in developing a participatory mechanism that contributes to expand the participation of IPLC-based networks.

8. Other terms often used interchangeably with ILK include Local and Indigenous Knowledge Systems (LINKS), Traditional Ecological Knowledge (TEK), among others.

Table 1 4 **Operationalization strategy for systematically including Indigenous and Local Knowledge (ILK) and issues of concern to Indigenous Peoples and Local Communities (IPLCs) in the global assessment.**

i. Question- based approach	Three overarching questions and 36 chapter-specific questions were developed to guide authors in literature review and to guide consultations and dialogues activities.	**Inclusive definition of IPLCs and ILK**
ii. Systematic and inclusive review of published evidence and geospatial data	The global assessment integrates evidences from multiple sources. 1) systematic literature search in indexed journals and search engines; 2) information from other IPBES assessments and proceedings of earlier ILK Dialogue Workshops; 3) geospatial data from international research centres and national institutions; 4) information derived from an on-line 'Call for Contribution' platform developed specifically for the global assessment; and, (5) inputs received from face-to-face presentations and consultations with IPLC networks and organizations. The chapters include over 3000 bibliographic references, including articles, books, and reports, relevant to ILK and IPLC issues.	
iii. Author's Liaison group	28 authors (Coordinating Lead Authors and Lead Authors) and 32 Contributing Authors directly participated in the analysis of evidence of literature on ILK/IPLCs. Several authors participated in dialogue and consultation workshops	
iv. Online Call for Contributions	An international Online Call for Contributions was carried out between August and December 2017 receiving 363 contributors from over 60 countries and providing over 1200 bibliographic resources.	
v. Face-to-face consultation and dialogues	Multiple forms of dialogues and consultations with representatives of IPLCs and the scientific community were carried out in international fora and community grounds involving representatives of Indigenous Peoples and Local Communities, experts and practitioners. These include: UN Permanent Forum on Indigenous Issues, USA, 2017, 2018; Dialogue on Human rights and Conservation, Kenya, 2017; Society of Ethnobiology, Canada, 2017; Arctic Dialogue, Finland, 2018; CBD: SBSTTA and 8j, Canada, 2017; Communities, Conservation and Livelihoods Conference, CCRN-IUCN, Canada, 2018; International Society of Ethnobiology, Brazil, 2018.	

Implementing an operational strategy for ILK and IPLCs in the global assessment: The global assessment builds upon these efforts to accomplish its mandate to include ILK and issues of concern to IPLCs as an integral part of the assessment process. To accomplish these goals, a scoping document and an operationalization strategy dedicated to IPLCs and ILK was developed at the onset, discussed and reviewed by multiple constituencies within IPBES and in dialogues with experts and IPLC representatives. This operationalization strategy was used to guide authors to coordinate activities within and across chapters. **Table 1.4** presents a synthesis of the scoping and operationalization strategy for the inclusion of ILK and IPLCs in the global assessment. This strategy includes five main components (see Supplementary Material 1.4): i. A question-based approach **(Box 1.4)**; ii. Systematic and inclusive review of published evidence and geospatial data; iii. A dedicated ILK liaison authors' group; iv. Online Call for Contributions; and, v. Dialogue and consultation with representatives of IPLCs and experts.

This strategy, particularly the detailed set of questions guiding this component within each chapter, set forward an ambitious agenda for synthesis and reflection on issues related to topics of concern to IPLCs and the contributions of their knowledge and practices to nature and its contributions to people. Because of data gaps and difficulties in integrating data from different parts of the world, languages, and representing different knowledge systems, responding to some questions has been challenging and, in some cases, only limited advances were possible. Consultation and dialogue workshops were organized and carried out in fora where representatives and experts from various regions and stakeholder groups could come together. The global assessment is also intended to help identify knowledge gaps, therefore the efforts presented here are also meant to encourage and stimulate research groups and practitioners working on different aspects of ILK and IPLCs, at different levels and regions, to carry out research and synthesis to inform future assessments.

1.3.3 Scenarios of future change

Two chapters of the global assessment review future scenarios and possible pathways to achieve them and consider the implications of achieving or missing of internationally agreed goals such as the Aichi Biodiversity Targets and the SDGs. In chapter 4, scenarios are used to explore a range of plausible futures, based on potential trajectories of direct and indirect drivers. Chapter 5, on the other hand, evaluates pathways and policy intervention scenarios in order to achieve desirable futures, paying particular attention to the interactions of various SDGs

Box 1 4 ILK/IPLCs Guiding Questions for the Global Assessment.

A question-based approach provided a common reference for authors to review empirical evidence and as a basis for consultations and dialogues activities. Three overarching questions were developed within the scope and mandate of assessment, which were then further detailed into 36 chapter-specific questions used to guide the work of chapters 2 to 6.

1. *'What have been the contributions of indigenous and local knowledge (ILK), practices, and innovations to the sustainable use, management and conservation of nature and nature's contributions to people at regional and global scales?*

   This question is based on accumulated evidence indicating that while knowledge, practices, and innovations of IPLCs related to nature are locally based, they are manifested in regional landscapes and ecosystems, and are globally relevant.

2. *'What are the most important features, pressures and factors related to and/or enabling or constraining these contributions, as well as impacting present and future quality of life of IPLCs?'*

   This question is based on accumulated evidence indicating that in many regions IPLCs are at the forefront of social, economic, political and environmental/ecological pressures that directly affect the environment; they are socially and economically marginalized and are experiencing high rates of social and environmental changes.

3. *'What policy responses, measures, and processes can contribute to strengthen and improve the institutions and governance of nature and its contributions to people with regard to IPLCs?'*

   This question is based on accumulated evidence recognizing an important role for IPLCs in supporting the global biodiversity strategy pre- and post-2020, the 2030 Sustainable Development Goals, and climate mitigation goals in the Paris Agreement on Climate.

Thirty-six chapter-specific questions are available in Supplementary Material 1.4. They include questions related to the management of landscapes, ecosystems and watershed, species diversity, agrobiodiversity, protected areas, institutions and customary systems, drivers of environmental and social change, climate change impacts and adaptation, the contributions of IPLCs to international conventions, among several others.

between now and 2050 (SDGs, 2050 Vision). The objective is to facilitate a better understanding of the types of socio-economic development pathways leading to outcomes that are closest or furthest to these goals. This complementarity between scenarios and pathways in the context of the IPBES conceptual framework and the global assessment is illustrated in **Figure 1.4 and Figure 1.6**.

In chapter 4, four main types of scenarios are distinguished: exploratory, target-seeking, policy screening, and retrospective policy evaluation **(Figure 1.6)**. The chapter focuses on exploratory scenarios, which assume the absence of explicit policy intervention, and often combine extrapolations of past trends with new assumptions. Exploratory scenarios are often developed using participatory methods and can be either qualitative, often in the form of storylines, or quantitative, often in the form of models (van Vliet & Kok, 2013). Some groups of scenarios developed in the last few decades share many aspects of their storylines and are considered here as "archetype scenarios"; these archetypes vary mainly in the degree of dominance of markets, globalization, and policies toward sustainability. Chapter 4 follows the IPBES methodological assessment on scenarios and models (IPBES, 2016b) for the adoption of 'scenario families' (van Vuuren *et al.*, 2012), also covering archetypes based on scenarios developed by the Global Scenarios Group (GSG) (Hunt *et al.*, 2012; Raskin, 2005). The scenarios analysed include those that are often restricted to particular temporal or spatial scales and limited in scope and incomplete regarding quantitative information about nature, ecosystem services, and quality of life. Although recent advances in integrated assessment modelling seek to overcome these restrictions (e.g., Harfoot *et al.*, 2014), important gaps related to conservation of biodiversity remain in global scenarios, such as integrated scenarios for vulnerable areas, and socioeconomic scenarios developed for and in collaboration with IPLCs (Furgal & Seguin, 2006).

In order to design the means of achieving international biodiversity targets and development goals, and to assess the role of biodiversity and ecosystems in achieving the SDGs, Chapter 5 examines recent knowledge about target-seeking or normative scenarios relating to nature, nature's contributions, and quality of life, and their interlinkages. The chapter focuses on both the quantitative aspect of scenarios, i.e., technical options, and their qualitative assumptions, i.e., how change will be addressed in terms of values, institutions and governance. In that sense, scenarios are viewed as plausible and relevant narratives about the future in the frame of major uncertainty, rather than forecasts or predictions (Ferrier *et al.*, 2016; Raskin, 2005). A clear distinction is made between the terms 'scenarios' and 'pathways'; while scenarios use narratives to explain outcomes generated by a model, pathways are possible trajectories toward the achievement of specific outcomes, for instance biodiversity conservation goals and targets in the context of the SDGs. Multiple scenario studies are combined here to inform such pathways, and three backbone angles are considered: a) different types of scenarios as developed in Chapter 4 (target-seeking, sustainability-oriented i.e., global and regional sustainability archetypes, and some policy-screening scenarios), b) a cross-scale focus (global to local as fine spatial resolutions provide contextual insights that global scenarios alone may not capture), and c) a nexus approach based on clusters of SDGs and complemented by relevant literature. Building on the IPBES regional assessments meta-analyses, Chapter 5 also seeks to give emphasis on local and participatory scenarios, especially visions based on ILK, highlighting how interactions between spatial and temporal scales are relevant for future pathways.

Scenarios, as a way of thinking critically about the future of nature and NCP, have the potential to feed major phases of decision-making in the policy cycle, from agenda setting and design to implementation and review. Accordingly, chapters 4 and 5 provide important elements for chapter 6 on policy options **(Figure 1.6)**. Policy and decision-making processes rely on estimates of anticipated future socio-economic pathways, and on knowledge of the potential outcomes of actions across distinct geographic regions, scales, sectors and social groups, especially in the face of high uncertainty and unpredictability (Peterson *et al.*, 2003). In the IPBES context, scenarios and models play complementary roles in describing possible futures for drivers of change or policy interventions and translating those scenarios into projected consequences for nature and its contributions to people (IPBES, 2016b)

1.3.4 Units of analysis

The subdivision of the Earth's surface into spatial units for the purpose of analysis is notoriously controversial and there is no single agreed-upon system that IPBES can adopt as its standard. The global assessment thus adopts the term 'Units of Analysis' also used in other IPBES assessments. The term Units of Analysis refers to a broad-based classification system at the global level, considering both the state of nature in classes equivalent to what is commonly called 'biomes' or 'ecoregions', and classes where ecosystem structure and function have been severely altered through human management, which can be called 'anthromes' or anthropogenic environments (Ellis & Ramankutty, 2008).

The classification of Units of Analysis was developed over several years of consultations with experts involved in various IPBES regional and thematic assessments as well as the global assessment. The current Units of Analysis took into account previous classifications of biomes, ecoregions

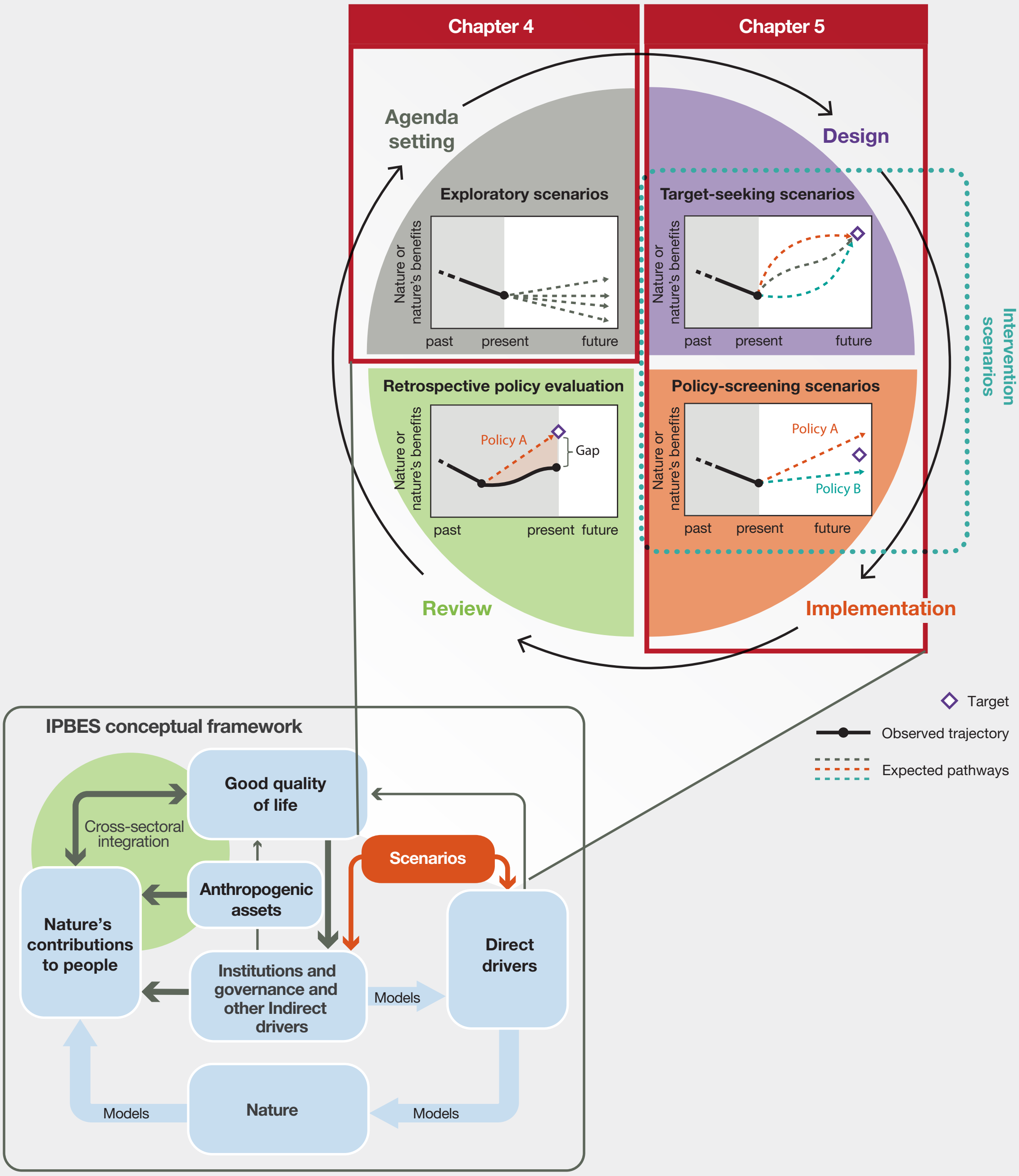

Figure 1 6 **Scenarios in the Global Assessment.**

The right-hand side of the figure shows what Chapters 4 and 5 assessed in terms different types of scenarios within major phases of the policy cycle. The left-hand side of the figure shows the relationships between scenarios (burgundy arrows), models (blue arrows) and the key elements of the IPBES conceptual framework. This figure was modified from the Summary for policymakers of the methodological assessment of scenarios and models of biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES 2016b).

(Olson *et al.*, 2001; WWF, 2018), Millennium Ecosystem Assessment reporting categories (MA, 2005) and regional habitat classifications (i.e., European nature information system, EUNIS; EEA, 2018). The goal of the Units of Analysis is to serve the needs of the coarse level of global analysis, reporting and communication in a policy context. Given differences among regions and the needs of regional assessments, this list of global units may not match the regional units.

#	UNIT OF ANALYSIS	TERRESTRIAL	FRESH-WATER	MARINE	HUMAN
1	Tropical/subtropical forests	xxx			
2	Temperate/boreal forests/woodlands	xxx			
3	Mediterranean	xxx			
4	Arctic and mountain tundra	xxx			
5	Tropical/subtropical grasslands	xxx			
6	Temperate grasslands	xxx			
7	Deserts and xeric shrublands	xxx			
11	Cryosphere	xx	x	x	
8	Wetlands		xxx		
13	Inland waters		xxx		
14	Shelf ecosystems			xxx	
15	Surface open ocean			xxx	
16	Deep sea			xxx	
9	Urban/Semi-urban	..	..		xxx
10	Cultivated areas	..	..		xxx
12	Aquaculture	..	..	..	xxx
17	Intensive/multiple use coastal areas	..	..	..	xxx
		8	2	3	4

The list of 17 global Units of Analysis includes 13 biomes, and 4 anthromes **(Figure 1.7)**. Of the 13 biomes, 7 are terrestrial, 2 are freshwater, 3 are marine and one cuts across all three. The four anthromes include 2 exclusively terrestrial ones, where ecosystem function is transformed to a very high degree from natural pathways to human ones – urban/semi-urban areas and cultivated areas. The aquaculture anthrome mirrors 'cultivated areas' but may be derived from terrestrial, freshwater or marine biomes. Finally, the 'intensely and multiply used coastal' anthrome reflects the unique position of the coastline and our use of it, sandwiched between land and sea and a nexus for terrestrial, marine, freshwater and climatic processes. The anthromes layer over biome units (e.g., a city in a grassland area) but are so transformed that the original biome may no longer exist there.

Definitions for each unit are given in Supplementary Material 1.5 and defined and examined more fully in Chapter 2.2 (Nature). They combine standard definitions (such as from existing biome classifications) and operational elements to cope with variation over the globe and data limitations for mapping and determining their precise boundaries.

1.3.5 Use of Indicators

The global assessment adopted a multi-dimensional system of indicators to examine status and trends, progress towards international goals such as the Aichi Biodiversity Targets and the SDGs, evaluate policy instruments, and consider plausible future scenarios. Indicators are considered synthetic forms of data, information, and knowledge that are harmonized to help understand the status, cause or outcome of an object or process both quantitatively and qualitatively. In other words, indicators are measures of different aspects of nature that help monitor, compare and communicate changes in the state of nature over time. Indicators have advantages and limitations depending on the scale of aggregation and/or how complex is the phenomena an indicator aims at expressing. Indicators are best seen as nested and can range from directly measurable parameters that are included in monitoring to aggregated indices. Standardized indicators are of great importance for assessments because they provide a common set of categories and common language to talk about status and trends in nature, thus providing common threads and quantitative points of comparison from which expert

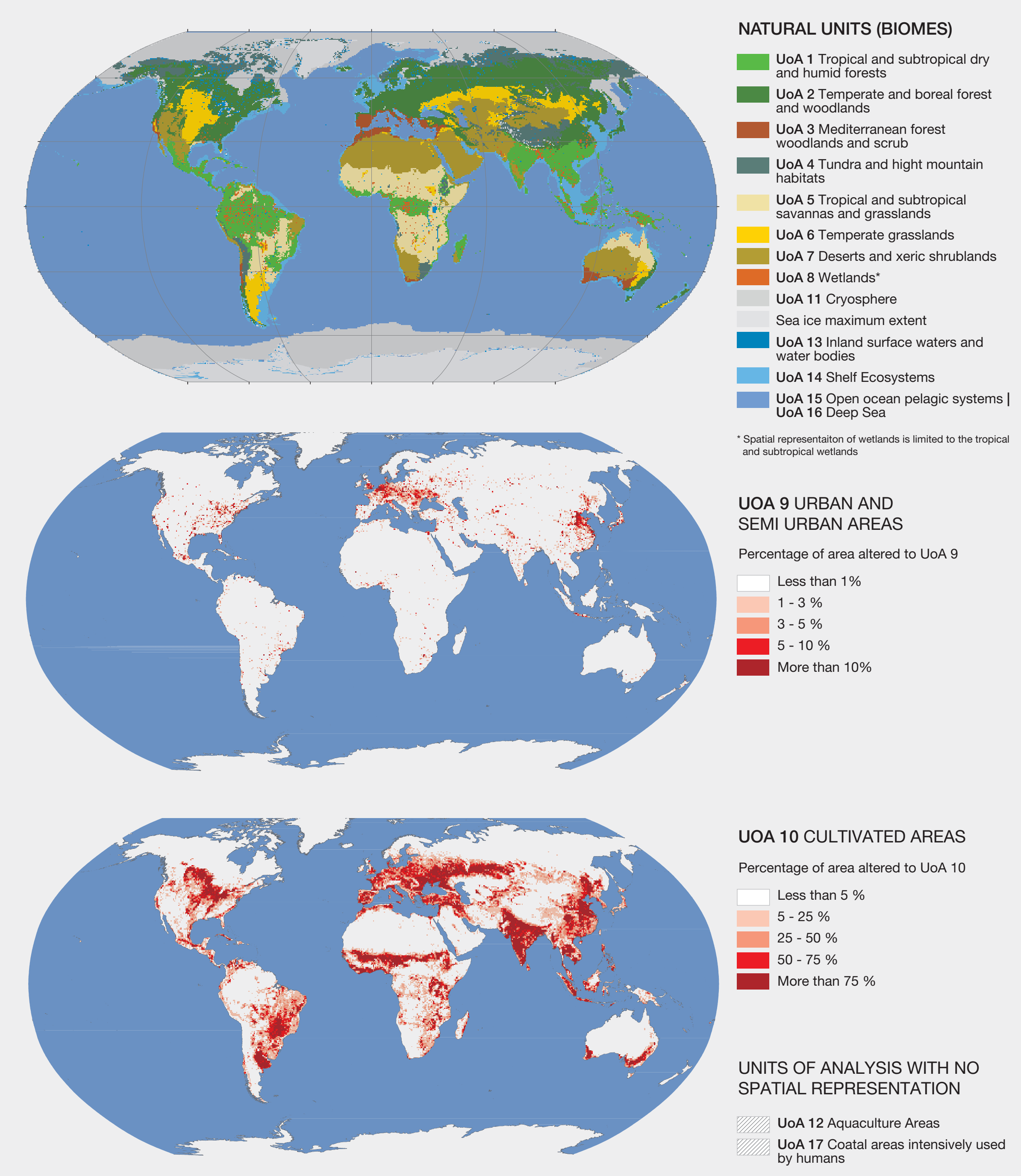

Figure 1 7 **Maps of the IPBES Units of Analysis; depicting both natural biomes and anthromes for the globe.**

The top map illustrates the biomes, followed by two maps of anthrome extent: urban and semi-urban areas (in the middle), and cultivated areas (in the bottom). Higher percentages of anthrome area are represented by deeper red tones. For more information on the description of IPBES Units of Analysis please see Supplementary Material 1.5.
Access the spatial data layers here: https://doi.org/10.5281/zenodo.3975694.

judgment can be deliberated (Turnhout, 2009; Turnhout *et al.*, 2007). Yet, as it has also been noted in the discussion of the NCP and values above, the selection of indicators reflects specific views and values.

Authors are aware of the limitations of indicators, both single or composite, to capture the complexities of the 'real world' or to represent different perspectives on a problem (i.e., proxy). Indicators are by nature restricted to what can be measured and for which there are available data at a given unit of analysis and resolution, ideally generated with the same methods, referring the same system boundaries, and being of comparable quality. These limitations are especially significant when it comes to nature's non-material contributions to people and aspects of a good quality of life, as well as to represent the perspectives of Indigenous Peoples and Local Communities. As no single indicator can provide information on all policy relevant aspects, assessments rely on selected sets of indicators that are available at, or that can be aggregated or scaled up to the global level. **Figure 1.8** shows a conceptual diagram illustrating connections among types of evidence as used in an assessment. The flow of data to information and knowledge relevant to an assessment involves both direct use and interpretation through different disciplinary and knowledge system lenses, such as how raw data on temporal or spatial variation in drivers and pressures on nature can be used independently or combined with other types of evidence to derive conclusions and inferences, such as those used for future projections.

The initial discussion of IPBES indicators began in 2015, aimed at providing common indicators for the IPBES

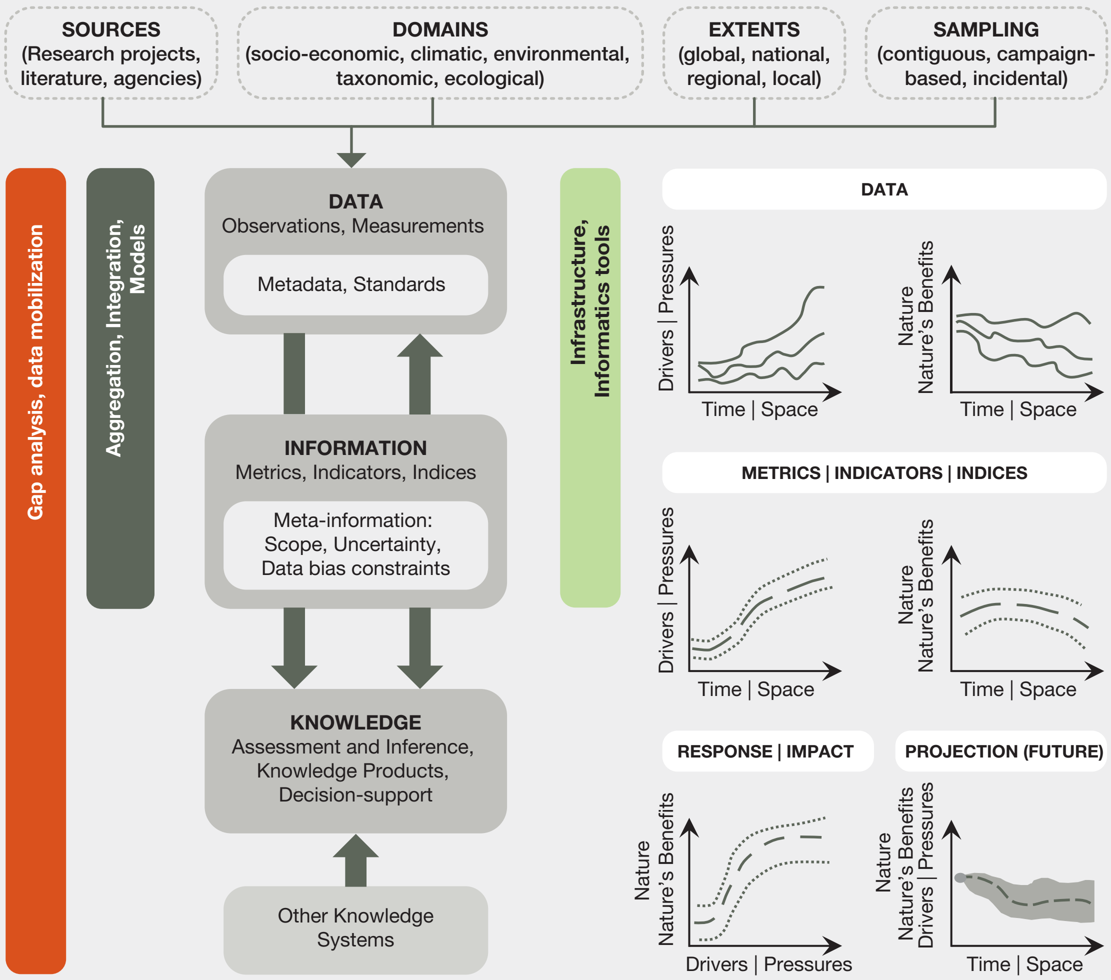

Figure 1 8 **Conceptual connection among types of evidence.**

The left side conveys the flow of data to information and knowledge relevant to IPBES, facilitated by a variety of approaches highlighted in colored boxes. Data may lead to knowledge directly or, outside this hierarchy of scientific inference, come from other knowledge systems. The right portion illustrates how raw data on temporal or spatial variation in drivers and nature (biodiversity and ecosystem properties and processes) may be combined to establish information about them, such as in the form of metrics, indicators or indices. Other knowledge systems directly contribute to assessment and inference for future projection. A combination of data or information from science and other sources contribute to knowledge about causal associations between drivers and impacts, which may then be used for projection. Source: Walter Jetz, Yale University.

For more information on the list of Core and Highlighted Indicators please see Supplementary Material 1.6 and 1.7.

Box 1 5 **IPBES principles for choosing indicators[6].**

1. **Policy relevant:** Indicators should provide policy-relevant information at a level appropriate for decision-making. Where possible, indicators should allow for assessment of changes in ecosystem status related to baselines and agreed policy targets.

2. **Scientifically sound:** Indicators should be based on clearly defined, verifiable, and scientifically acceptable data, collected using standard methods with known accuracy and precision or based on traditional knowledge that has been validated in an appropriate way.

3. **Simple and easy to understand:** Indicators should provide clear, unambiguous information that is easily understood. It is important to jointly involve policymakers, major stakeholders, and experts in selecting or developing indicators to ensure that the indicators are appropriate and widely accepted.

4. **Practical and affordable:** Obtaining or using data on the indicator should be practical and affordable.

5. **Sensitive to relevant changes:** Indicators should be sensitive and able to detect changes at time frames and spatial scales that are relevant to the decision-making. At the same time, they should be robust to measurement errors or random environmental variability in order to prevent "false alarms". The most useful indicators are those that can detect change before it is too late to correct the problems.

6. **Suitable for aggregation and disaggregation:** Indicators should be designed in a manner that facilitates aggregation or disaggregation at a range of spatial and temporal scales for different purposes. Indicators that can be aggregated for ecosystem as well as political boundaries are very useful.

regional assessments process; this originally involved regional assessment authors and experts of the IPBES Knowledge and Data Task Force, specifically, the task group on indicators. In addition to indicators related to Quality of Life **(Table 1.1)**, two main sets of biodiversity-related indicators were considered in the global assessment: 1) Core Indicators (n=30) and 2) Highlighted Indicators (n=42), which are presented and described in Supplementary Materials 1.6 and 1.7. Assessment authors used all available core and highlighted indicators in addition to other indicators or data sources they considered appropriate based on expert judgment (see **Box 1.5**).

Complementary sets of indicators were used when needed and available for analysing the Aichi Biodiversity Targets and the SDGs, which have their specific lists of indicators associated with different targets and goals. Chapters 2 and 3 also benefited from using indicators considered more relevant to Indigenous Peoples and Local Communities. In the case of Chapter 3 this was done through a systematic literature review for each Aichi Biodiversity Target and SDG analysed. Chapter 2 also considered indicators from and relevant to Indigenous Peoples and Local Communities as applied to different units of analysis.

Finally, at the level of experimentation, the global assessment piloted the concept of 'bundles of social-ecological indicators' (SES indicator bundles) with the theme of food security. Following a targeted workshop held around this theme, multiple bundles of indicators were identified tying together socio-ecological indicators with existing IPBES Core and Highlighted indicators. This category of social-ecological indicators emerged from the process of identifying Core and Highlighted Indicators as it became evident that there are large gaps in the existing indicator sets relevant to IPBES assessments in terms of evaluating the relationships embedded in the IPBES conceptual framework, including nature's contributions to people and good quality of life. Although these SES indicators and their bundles were used only experimentally, the piloting exercise provided useful guidelines for authors to examine issues of food security using as many and diverse indicators as possible.

1.3.6 Literature review

The scope of the IPBES global assessment is vast, examining past, present and possible future trends in multi-scale interactions between people and nature, taking into consideration different worldviews and knowledge systems. Within the science-policy interface the challenge is to approach, package and communicate the findings, which emerged from systematic evaluations of evidence in combination with input from transparent and open reviews, in a way that can be accessible and useful to decision makers.

The global assessment is based on existing data (including, as appropriate, national data), published scientific and grey literature and other information, including indigenous and local knowledge (see section 1.3.2.2), according to the guidelines of IPBES. Grey literature includes government publications, policy documents and briefs, online publications, technical reports and datasets etc. Based on the broad search strings and filters for output

9. Guide on the production and integration of assessments from and across all scales (deliverable 2 (a)); Modified from Ash et al. 2010 IPBES/4/INF/9 – IPBES Guide on the production and integration of assessments from and across all scales (deliverable 2 (a)).

results for systematic reviews in various databases/search engines, grey literature was not excluded from output results and held to the same criteria as all other literature and publications. The global assessment also considers IPBES' regional, thematic and methodological assessments and guidelines, as well as other relevant global assessments such as the Global Biodiversity Outlook series, the IUCN Red List of Threatened Species, assessments by the Food and Agriculture Organization of the United Nations, the Global Environmental Outlook series, the reports of the Intergovernmental Panel on Climate Change (IPCC), the Millennium Ecosystem Assessment, the first World Ocean Assessment (WOA I) and other assessments prepared under the Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including socio-economic aspects.

How authors approach the assessment of the growing evidence base is a critical step in how the key findings are developed. Apart from this Chapter 1, all chapters used a combination of systematic and expert-based reviews to evaluate available evidence. A flexible protocol for systematic review was developed as a framework to guide authors, based on methods developed by the Collaboration for Environmental Evidence (2013)[10].

The suggested protocol within the global assessment aimed to achieve:

- **Transparency:** methods for identifying and selecting resources are reported;
- **Equivalent quality across chapters:** each chapter follows a similar approach;
- **Reduced bias:** resources known to authors are weighed against the best available resources; published and grey literature are searched concurrently;
- **Repeatability:** methods of identifying resources can be repeated or refined in subsequent assessments;
- **Efficient use of author time:** clear guidelines on how to search helps authors plan their work;
- **Efficient use of existing resources**: international efforts to compile environmental evidence for policy and practice are actively incorporated;
- **Balance** between the rigor of systematic review and the timeline and literature cut-off dates of an IPBES assessment.

The process involves two main sequential steps: 1) when applicable, concurrent database searches of different kinds of literature (e.g., peer reviewed and "grey" published literature, unpublished but openly available reports and databases) to minimize potential biases and 2) personal knowledge and experience of authors regarding key seminal resources or publications not appearing as an output from first step. The cut-off date for the inclusion of published sources was 30 April 2018. However, exceptions for including sources published after this date were made on the basis of reviewers' comments and the publication of relevant new evidence. In addition to systematic literature reviews carried out across chapters, an additional effort was made in chapter 3 to carry out systematic literature review to evaluate each Aichi Biodiversity Target and relevant SDG from the perspective of Indigenous Peoples and Local Communities. 32 Contributing Authors were involved and a total of 1760 literature references were compiled and analysed for this purpose (see chapter 3). In addition to this systematic review, the analysis of ILK/IPLC issues also benefited from an "Online Call for Collaboration"[11] (Table 1.4, Supplementary Material 1.4), which contributed around 1200 references, which were reviewed and selected to inform specific sections of the assessment.

In most cases, the method for literature review also included a priority order for inclusion of scientific evidence in the assessment: **Collated synopsis or summary > Systematic Review > Meta-analysis > Review >Individual Studies or case studies > compiled expert opinion.**

This order of priority assumes resources at each level are of equivalent quality and relevance. A combination of resources was discussed by authors to represent the most relevant and highest quality evidence. During chapter meetings, authors discussed the highest level of synthesis available as a priority and supplemented with levels below if necessary to fully cover and evaluate the subject/topic, or to include the most up to date information.

Across all chapters of the global assessment in the underlying chapter text, references are cited in-text with the full reference at the end of each chapter. Across all chapter executive summaries and the summary for policymakers' background text, traceability is indicated to chapter subsections enclosed in curly brackets. Each chapter includes a discussion of the literature review process in the main text or as part of the chapter's supplementary materials.

10. http://environmentalevidence.org/wp-content/uploads/2014/06/Review-guidelines-version-4.2-finalPRINT.pdf

11. Launched 25 July 2017.

1.3.7 Confidence framework

A qualitative method of communicating the level of uncertainty and confidence in a key finding or statement using accessible and agreed upon terms and language has been essential to communicate assessment findings to decision-makers. The evaluation of confidence of assessment findings in the global assessment is based on the experience of previous IPBES assessments, which in turn benefited from other international and intergovernmental assessments, such as the Millennium Ecosystem Assessment, the Intergovernmental Panel on Climate Change (IPCC), and the UK National Ecosystem Assessment (UK-NEA).

The global assessment followed the schematics and criteria presented in **Figure 1.9** to guide authors in the process of assessing and communicating the degree of uncertainty, or confidence, related to key findings. This four-box confidence framework developed for IPBES assessments and its key findings are based on level of agreement of experts using their judgment (x-axis) in combination with the quantity and quality of evidence assessed (y-axis – **Figure 1.9**). The evidence includes publications, data, theory, models and information etc. Further details of the approach are documented in the note by the secretariat on the information on work related to the guide on the production of assessments (IPBES/6/INF/17).

The summary terms to describe the evidence are:

- ***Well established:*** comprehensive meta-analysis or other synthesis or multiple independent studies that agree.
- ***Established but incomplete*:** general agreement although only a limited number of studies exist; no comprehensive synthesis and/or the studies that exist address the question imprecisely.
- ***Unresolved*:** multiple independent studies exist but conclusions do not agree.
- ***Inconclusive*:** limited evidence, recognizing major knowledge gaps.

Following other IPBES assessments, the global assessment does not use a likelihood scale or probabilistic certainty scale.

The synthesis of this large volume of evidence is challenging and complex and relies strongly on authors' expertise and joint deliberations, including authors from multiple disciplinary backgrounds and knowledgeable of issues related to other knowledge systems, particularly Indigenous Peoples and Local Communities. These confidence terms inform and communicate to decision-makers what the assessment author teams have high confidence in as well as what requires further investigation to allow decision makers to make informed decisions.

Figure 1 9 **The four-box model for the qualitative communication of confidence.**

Confidence increases towards the top-right corner as suggested by the increasing strength of shading. Source: IPBES (2016).

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Chapter **2.1**

STATUS AND TRENDS – DRIVERS OF CHANGE

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CHAPTER 2.1 STATUS AND TRENDS – DRIVERS OF CHANGE

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CHAPTER **2.1**

STATUS AND TRENDS – DRIVERS OF CHANGE

EXECUTIVE SUMMARY

Global transformation involved key trade-offs, and inequalities, as growing interactions drove economic growth but also degradation.

Accelerations in consumption and interconnection have had trade-offs.

i. Meeting basic material needs, and rising hopes of growing populations has had trade-offs. Nature has been degraded by the aggregated impacts of myriad actions (*well established*). Today, humans extract more from the earth than ever before (~60 billion tons of renewable and nonrenewable resources) {2.1.2} with population doubling over 50 years {2.1.4} and the per person consumption of materials up 15% since 1980. Since 1970, global extraction of biomass, fossil fuels, minerals, and metals increased sixfold {2.1.6, 2.1.11, 2.1.14}. Urban area doubled since 1992 and half of agricultural expansion (1980–2000) was into tropical forests {2.1.13}. Fishing now covers over half the ocean {2.1.11}. Since 1980, greenhouse gas emissions doubled {2.1.11, 2.1.12}, raising average global temperature by at least 0.7 degrees {2.1.12} and plastic pollution increased tenfold {2.1.15}. Over 80% of global wastewater is discharged into the environment without treatment, while 300–400 million tons of heavy metals, solvents, toxic sludge, and other wastes are dumped into the world's waters each year {2.1.15}. Fertilizers enter coastal ecosystems, producing more than 400 hypoxic zones and affecting a total area of more than 245,000 km^2 {2.1.15}. The number of recorded invasive alien species doubled over 50 years {2.1.16}. Today, a full 75% of the terrestrial environment, 40% of the marine environment, and 50% of streams manifest severe impacts of degradation {2.1.12}.

ii. Accomplishments and shortfalls in the past – and the futures that we will shape – follow from variations in values, demography, innovation, trade and governance *(well established)*. Over the last 50 years, utilitarian instrumental views framed nature chiefly as a source of inputs, although narrow views have been challenged by varied institutions {2.1.3}. Irrespective of values, our increasing numbers drive degradation. Urban concentration shifts the trade-offs that we face {2.1.4}, while education affects changes in populations and per-person degradation – potentially at the cost of losses of the knowledge held by IPLCs {2.1.4}. Scarcities in nature's contributions have driven innovations that shift trade-offs, from the Green Revolution to massive hydroelectric dams, with genetic engineering, fracking, wind power, and other trends all to be fiercely debated {2.1.5}. The diffusion of such innovations could lower total degradation, while globalization has shifted degradation far away from consumption {2.1.5, 2.1.6}. Local community governance has organized more sustainable production {2.1.8} while nations, as 'global community citizens', have initiated a range of governance agreements, which had a range of fates. Nations also have adopted domestic conservation policies and even adjusted economic policies for nature {2.1.9, 2.1.10}. Supply chains are challenging national governance yet also signaling citizens' environmental preferences {2.1.7}.

iii. Within and across countries, outcomes trajectories have been unequal – for nature, for basic individual human needs, and for aggregate economic growth rates (*well established*). Forest cover stabilized in high income countries but since 1990 fell 30% in low income countries {2.1.11} as agricultural area fell in the former but rose in the latter {2.1.11, 2.1.13}. Natural assets values fell 1% in low income countries, since 1995, yet rose 5% in middle and upper-middle income countries {2.1.2, 2.1.13}. While 860 million people face food insecurity in Africa and Asia, obesity is rising in high and middle income countries {2.1.2}. Per capita demand for materials from nature is four times higher in high and low income countries {2.1.2}. Per capita consumption of animal protein rose by 50% during 1960–2010, to ~55 g/capita/day within the US and the EU, and ~30 g/capita/day in Latin America, but only ~15 g/capita/day in Asia and sub-Saharan Africa {2.1.2}. Contrasts are clear in the satisfaction of basic needs and the maintenance of nature and the two are linked, e.g., 40% of the globe's population lacks access to clean and safe drinking water and the highest gaps drive up child mortality in Africa {2.1.2}. Environments-based health burdens (e.g., air or water pollution) are born by people with lower-income {2.1.2, 2.1.15}, while GDP per capita is 34 times larger in developed than in developing countries and still it is rising faster within the former {2.1.2}.

I. Indirect Drivers: The root causes of transformations – both pros and cons

Values, demography, innovation, trade and governance drive outcomes

I-A. INDIRECT DRIVERS – VALUES

1 **The ways in which nature is conceived of and valued have had enormous implications for different consumption and production choices that influence degradation (*well established*).** Values differ across people, and evolve over time, informed by cultures and experiences {2.1.2.3}. Values toward nature may be grounded in ethical principles, and relationships, or predominantly utilitarian, focused on immediate preferences or leaning toward consideration of the future {2.1.2.3}. Globalization, migration, urbanization, and climate change are disruptors that can catalyse shifts in values towards nature {2.1.3}. Relational worldviews and values with strong ties to the land are central in many cultures around the world, associated to self-imposed restriction based on norms {2.1.3}. Narrower utilitarian, instrumental views of nature as a source of economic inputs, though, underpinned a variety of actions that promote resource extraction, industrialization, urbanization, and global trade, which continue to intensify {2.1.3}. Such views have been challenged in the last fifty years by calls for other ethics to mediate the interactions among and between humans and nature {2.1.3}. Examples of such narratives are the "living in harmony with nature" principle of the Rio 1992 Summit of The Earth conference, the Mother Earth emphasis within "the future we want" vision from Rio+20, and Pope Francis' recent encyclical {2.1.3}. Such visions of well-being and links to nature clearly have evolved over time {2.1.3}. For instance, if nature is degraded over time, while economies grow, core values may shift from a narrower orientation toward economic development to an integration of other dimensions such as varied capacities, justice, security and equity – all linking with nature in different ways {2.1.3}. Yet, stepping back, while all these views contributed to conservation and restoration in some locations, at the global level degradation of nature has continued despite increasing high-level awareness of degradation and scarcity {2.1.3}.

I-B. INDIRECT DRIVERS – DEMOGRAPHY

2 **For any values, population size is a big factor in scales of degradation (*well established*).** Human population has been growing, globally, doubling since 1970 overall, and despite regional variations this growth is expected to continue – with implications for degradation {2.1.4, 2.1.13}. The largest current increases are in least developed countries and in Africa, where the total population doubled, yet countries are starting to experience decreases, as developed countries have experienced in the past {2.1.4}. That said, those decreases in fertility rates result not from an automatic 'demographic transition', based upon economic development alone, but instead from conditions including women's empowerment and their access to family planning methods {2.1.3}.

3 **Education causes and is caused by economic growth – which in turn degrades, lowering human capital – yet education also can influence the rates of degradation *(well established)*.** Education has increased globally, in particular for women, with implications for human capital accumulation and, thereby, use of nature {2.1.4}. Together, those capital assets form a large share of national wealth, in particular for lower-income countries, and support an ongoing investment in education {2.1.4}. Environmental education can support lower degradation per unit of economic growth, through shifts in both production and individual habits {2.1.4}. This has benefits for human capital, as for example pollution lowers human productivity {2.1.4, 2.1.13}.

4 **Appreciation of indigenous and local knowledge (ILK) for managing nature is rising yet, at the same time, these local knowledge systems continue to be degraded (*well established*).** Indigenous and local knowledge (ILK) generated within IPLCs increasingly is seen as relevant for sustainable production. It offers broadly applicable alternatives to centralized and technically oriented solutions, which often have not substantially improved prospects for smaller producers {2.1.4, 2.1.5, 2.1.11, 2.1.13}. Yet, at the very same time, values and knowledge change with exposures including formal education, which can erode local worldviews that prioritized nature {2.1.3, 2.1.4}.

5 **Migration is both a cause and an effect of nature's degradation. Links in both directions are connected to patterns of vulnerability, in rural as well as urban areas (*well established*).** Migration has increased greatly, with 264 million international migrants entering other countries since 1970: more to developed countries {2.1.4}. Environmental and economic factors contribute to this migration. Today, environmental migrants number several million {2.1.2, 2.1.4} given inequity across regions in conditions for well-being and in provisioning and regulating contributions from nature that are among the most important determinants {2.1.2, 2.1.4}. Immigrants are often among the most vulnerable groups in society, with low access to nature's contributions to basic needs (water, sanitation and nutrition), yet they can have impacts on how nature is managed, including due to differences in values {2.1.2, 2.1.4}.

6 **Urbanization has been rapid, with enormous consequences including spatial patterns of land use**

that affect nature and NCP provision in urban and rural areas (*well established*). Today, close to 60% of the world's population lives in cities, with the fastest increases in Asia and the Pacific (25% rise in urban share in 1980–2010) and Africa (37%). There are 2.8 billion people now in megacities, with the fastest growth in low- (45% since 1980) and lower-middle income (39%) countries {2.1.4}. In the developing world, many of those people live in slums, with a low quality of environment and life {2.1.4}. Cities are sources of innovations in transport, industry and medicine, however, their high densities affect spatial patterns of land use and, thereby, nature {2.1.4}. Urban consumers have huge impacts and thus the potential to drive global changes {2.1.4}.

I-C. INDIRECT DRIVERS – TECHNOLOGY

7 **By region, IPLC practices are expanding in their use or disappearing (*well established*).** Much of the globe's population appropriates natural resources via rural or primary management of terrestrial, marine and freshwater ecosystems {2.1.2, 2.1.4, 2.1.5}. Related IPLCs practices based on long-standing knowledge of complex local ecological systems are seen to be resilient in IPLCs and among small-holders who together are ~2 billion people with 25% of land {2.1.5}. For instance, the agroforestry systems in many tropical countries have common characteristics: highly diversified, productive, complex, and using rotations in agriculture – as well as grazing, hunting, and fishing {2.1.5}. Yet a combination of lifestyle change, adaptation to climate change, seasonal migration, enclosures, privatization, and degradation of resources is strongly affecting both the settlement patterns and the lifestyles of the peoples who manage directly these diverse systems {2.1.5}.

8 **Technological advances in agriculture brought new benefits and costs (*well established*).** The Green Revolution brought opportunities and risks – exemplifying the need to consider both social and environmental trade-offs of innovations that benefit aggregate economic output {2.1.5}. Yields of rice, maize and wheat all increased, steadily, through greater application of irrigation, fertilizers, machinery, and seed varieties with higher yields and resistance to disease {2.1.5}. Yet despite aggregate gains, there were losses for some groups and for the environment (all raising possible trade-offs in agricultural genetic engineering) {2.1.5}. Food security may have fallen, for some, as production shifted from subsistence approaches which had fed Indigenous Peoples and Local Communities to monocultures that offered lower nutrition and access to markets {2.1.2, 2.1.5}. Further, despite greater food availability famine continued given institutional failures {2.1.2, 2.1.5}.

9 **Transitions from biomass to other energy sources have large impacts (*well established*).** Innovations have also greatly shifted how energy is produced and used around the world {2.1.5}. More than in other regions, households in sub-Saharan Africa and East Africa in particular still depend on biomass for domestic energy supply (and some high income countries are promoting renewable woody biomass). By setting, this can adversely affect human health and provision of contributions such as climate regulation and species habitats {2.1.5}. Information constraints, costs of capital, cultural preferences, and slow development of market institutions inhibit adoptions of modern fuels (e.g., liquid petroleum gas or electricity) {2.1.5}. The resulting deforestation not only lowers multiple contributions from nature but also threatens local supplies of energy {2.1.5, 2.1.12}. Demands for energy are also increasingly met by hydroelectric dams, with projected expansions in Latin America, Africa and Asia – again changing the production-degradation trade-offs {2.1.5}.

10 **Scarcity of nature's contributions has motivated various adjustments (*well established*).** Scarcities due to the degradation of nature have motivated shifts towards methods of production with lower material or environmental intensities {2.1.2.1}. For instance, households invest in cleaner stoves when rising incomes raise food consumption and thus also fuels consumption for cooking, such that indoor air quality falls {2.1.5}. Information on water quality motivates purification efforts from village infrastructures to household filters and bottled water {2.1.5}. In irrigation, scarcity of water quantity drives societal innovation like upstream-downstream allocation committees {2.1.5}. High prices for fossil fuels inspire novelties from rural extensions of electric grids to solar lamps and wind energy as well as batteries to store the output {2.1.5}. Positive effects of such innovations include those from their diffusion {2.1.5}. Broader use allows low income countries to avoid more environmentally destructive stages of economic growth by 'leapfrogging ahead' to more modern technologies of production with less degradation per unit of output {2.1.2.1}. Policy innovations may seek to spur such private innovation and adoption in light of critical degradations of nature {2.1.5}. Concerns about climate change, for instance, have led to proposals for carbon taxes, so that fuel and other prices reflect degradation and spur innovation in both mitigation and adaptation {2.1.5}.

I-D. INDIRECT DRIVERS – ECONOMY

11 **Transitions across sectors greatly influence the degradation of nature (*well established*).** As economies have grown, since 1950, many have shifted from agriculture toward both industry and services {2.1.6}, resulting in far higher shares in agriculture for value added, and employment, for the low income countries {2.1.6}. This affects management of nature, given that industrialized economies are characterized by the lowest materials intensities {2.1.6} – although we must keep in mind that this is due in part to their imports of agriculture (see below). At 0.5 tons of

domestic material consumption per US$1000 GDP, Europe and North America had the lowest 2013 intensities (down from 0.8 and 1 in 1980, respectively) {2.1.6}, as influenced by the methods noted above as well as sectors characterized by lower material per unit of economic output {2.1.6}. Yet even material efficiency can be swamped by rising production {2.1.6} and, while Asia's intensity remained relatively constant at ~2.5 tons per $1000 US GDP between 1980 and 1992, since 2003 intensity rose again, reaching 3.1 tons in 2013 – with immense impact on average global intensity {2.1.6}. African economies still have the highest intensities but gains over 3 0 years have been significant, e.g., from 4.2 tons per $1000 US GDP in 1980 to 3.3 tons in 2013 {2.1.6}. Evidence is mixed for time paths as economies grow, with the scale of consumption potentially offset by the mix of what is consumed and the way in which it is produced. Forests show reversals from degradation to recovery, while different pollution types have mixed paths, including due to trade {2.1.6, 2.1.13}.

12 Concentration of output and funds – sometimes associated with industrial innovation – influences what is produced and who benefits within and across countries (*well established*). Today, a few corporations and/or financiers often control large shares of the flows in any market, as well as amounts of capital assets that rival total revenues for a vast majority of countries {2.1.6}. These concentrations and their locations can hamper nature governance efforts (see below) {2.1.6}. Related, increasing shares of relevant sectors (e.g., coffee, fruits & vegetables, textiles & apparel, furniture) are supplied through value chains featuring considerable power at the retail ends {2.1.6}. This affects bargaining in exchanges of labor, and goods made with natural resources, including in the agricultural, fisheries and forestry sectors {2.1.6}. The location of power additionally affects regulatory oversight, with respect to environmental and social issues {2.1.6} – e.g., infrastructure development is known for its murky oversight and for its impacts upon nature. Funding via tax havens provided 68% of foreign capital for Amazonian soy and beef production and supported 70% of the vessels that are implicated in illegal, unreported and unregulated fishing {2.1.6, 2.1.11}.

13 Expanding trade means consumption affects degradation elsewhere (*well established*). Domestic material consumption per capita is highest for the developed countries and rapidly increasing for developing countries {2.1.2, 2.1.6}. Net goods flows vary, with some countries exporting more and others importing more {6}. Generally, developed countries reduced agricultural outputs over the last 50 years {2.1.6, 2.1.12}, and domestic water footprints, while importing crops from low income countries {2.1.6}. Environmental degradation from the production of those traded goods should be taken into account in assessing importing countries' net impacts, as total impacts can rise as domestic degradation falls {2.1.6}. This all influences equity too, e.g., whether in current market institutions suppliers of resources get 'equitable' compensation {2.1.6}. Different trade-offs arise when forest in low income countries is conserved by importing from high income countries, which can occur when efficient uses of capital lower the total areas in production – a phenomenon that may lower local incomes in that sector or spur other local sectors {2.1.6, 2.1.13}.

I-E. INDIRECT DRIVERS – GOVERNANCE

14 Pro-environmental signaling from consumers has grown, within multiple supply chains, yet the documentation of significant impacts on nature has been limited *(well established)*. Consumers at the ends of supply chains increasingly request information about the practices and the degradation linked with production. It can be facilitated by civil society, even across borders, as third parties collaborate with all of the private actors engaged in varied exchanges {2.1.6, 2.1.7}. Sustainable production certifications, terrestrial or marine, have risen greatly – for practices both environmental and social – yet despite some positive anecdotes, large impacts remain rare {2.1.6}.

15 Community governance has reduced or reversed degradation *(well established)*. Local actors have often conserved nature in common property systems – using local information, social norms, and abilities to impose cost {2.1.2, 2.1.8}. For centuries, IPLCs have contributed in this way to regional economies. In recent decades, the share of resources such as forests governed by Indigenous Peoples and Local Communities has grown {2.1.8}. Governance of shared resources can be facilitated by access to resources and information sharing; for instance, the unassessed smaller fisheries have fared worse {2.1.8}. Lacking comprehensive global data, we have sufficient cases of both successes and failures to have learned that community governance can be effective, yet it is not always {2.1.8}, and successes may rely in part on the roles of formal governments – e.g., without the public defense of local rights to manage resource and to exclude others, community areas of terrestrial and aquatic resources can be invaded and local efforts thus undermined {2.1.8}.

16 Public clarifications of rights influence investments that affect nature *(well established)*. Allocating private rights may generate conflicts concerning fairness or equity – yet clear rights can improve the efficiency of both investment and management by, e.g., smallholders who are incentivized to monitor nature locally, as for terrestrial multiple-use protected areas {2.1.8, 2.1.9}. Clear examples of the importance of rights also exist for large- and small-scale fisheries which used rights-based governance to maintain fish stocks {2.1.8}. Successes in management have been more frequent when such local rights were established in ways that respected local procedures. When government ignores local governance, public interventions can be destructive {2.1.8, 2.1.9}.

17 Public facilitation of sustainable land-use practices – such as agroforestry, agroecology – shows promise and perhaps potential for upscaling *(well established)*. With appropriate support, both financial and non-financial, sustainable agroecological practices have restored nature and its contributions. At varied scales, these have been observed in multiple locations across the globe from farmer-managed regeneration in dry parkland forests in Africa to a variety of Indigenous Peoples and Local Communities forests which function under forestry certifications {2.1.8}. Yet there can also be spillovers from such intervention – e.g., raising forest cover within a country may be facilitated by degradation elsewhere, as forest clearing simply shifts (see Asian examples) {2.1.8}.

18 Leading economic policies (e.g., roads, credit, private rights) can be adjusted to lower degradation of nature and potentially at a low cost to affected economies *(well established)*. One way governments stimulate economies is by investing in infrastructures for transport {2.1.9}. An obvious option to reduce its degradation is planning the routes for economic corridors {9}. With good local information, and processes, this can lower the costs of satisfying all stakeholder safeguards. Another core policy is establishing and enforcing clear tenure {2.1.8, 2.1.9}. Clarifying smallholder rights, including around customary tenure, can lower natural degradation {2.1.8, 2.1.9}. Further, it can spur greater investment in productivity, including within sustainable approaches.

19 Popular economic subsidies to degrading behaviours can be adjusted *(well established)*. Subsidies to various forms of energy (gasoline, electricity, etc.) are common and popular {2.1.9}. Possible adjustments include maintaining income transfers while removing price distortions that have raised environmentally damaging behaviours {2.1.9}. Alternatively, such credits, or transfers, can be made conditional on environmental metrics (just as in conservation policies below) {2.1.9}.

20 Public conservation policies like protected areas (PAs) and payments for ecosystem services (PES) reduce degradation if pressure was confronted and local actors engaged *(well established)*. A growing set 'payments for ecosystem services' (PES) compensate local actors for restrictions on uses of nature {2.1.9}. States also directly restrict production or extraction as in protected areas, the most extensive conservation measures, and undertaken costly actions to restore nature {2.1.9}. The gains for nature from such interventions have ranged from none to quite significant, based on whether and how pressures were confronted and if that included engaging with locals {2.1.9}. Impacts have been more common in high income countries, although funding transfers support interventions in low income countries that provide global public goods (e.g., carbon storage and habitats) {2.1.9}. Restrictions in low income countries can have positive local outcomes if support is provided yet unless local actors are a focus, economic costs can be higher than local benefits {2.1.9}. Generally, equity considerations can shift the choices and implementation of such policy. Policies' benefits and costs often are not equally distributed across either income levels or other dimensions, including race, though who bears the burden varies greatly with varied use patterns. Rights allocations and subsidies affect disparities, in either direction – again varying by context.

21 Governments have coordinated to reduce some types of degradation *(well established)*. National borders limit governance of transboundary resources. While various global 'commons' are judged to be worth conserving, including outside of national jurisdictions, accountability for failures of sustainable management there has been, at the least, uneven {2.1.10}. Like individuals in communities, nations can agree upon self-regulations that aid global 'commons' by mutually limiting degradation, even when facing high costs of organizing restrictions, as well as threats to their stability based on nations' political shifts over time {2.1.10}. For global coordination such as about biodiversity, the ozone layer, the climate system, the oceans, and poles, the coordination of actors can be even more difficult than for local communities {2.1.10}. Still, even if some policies have not had short-run impact, efforts are ongoing. For example, a relatively recent endorsement by 170 states of FAO's Code of Conduct for Responsible Fisheries (CCRF) in 1995, as well as a growing endorsement of The Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing, which came into force in June 2016 (now with 54 countries), have contributed to a lowering of illegal, unreported, and unregulated fishing {2.1.10}.

II. Direct Drivers

Demands have led to varied actions with multiple impacts upon nature

II-A. DIRECT DRIVERS – SECTORS (actions that link indirect drivers to aggregated impacts)

22 Fisheries have the largest footprint – with all of industrial extraction, aquaculture and mariculture, and the small fisheries critical for the livelihoods of millions *(well established)*. Today, industrial fishing has a footprint four times larger than agriculture, in which more than the 70,000 reported industrial fishing vessels cover at least 55% of the oceans – with hotspots for fishing in the northeast Atlantic, northwest Pacific, and upwelling regions off South America and West Africa {2.1.11}. Smaller fisheries account for over 90% of the commercial fishers (over 100 million people), as well as nearly half (46%) of the total global fish catch, yet the rest of global fish production is quite concentrated, within a few countries and a few corporations. Knowledge of inland fisheries is limited, despite their societal and ecological significance (accounting for up to 12% of global fisheries production). The contribution of aquaculture and mariculture to global fish production is increasing (6–9% growth in 1990–2012), with mixed effects upon coastal and marine ecosystems. While nearly 75% of the major marine fish stocks are currently depleted, or overexploited, since 1992 the global fishery community has incrementally adopted sustainable development principles created under the umbrella of mainstreaming biodiversity in fisheries.

23 **Agriculture, including grazing, has immense impacts upon terrestrial ecosystems, with important differences depending upon enterprise's intensity and size *(well established)*.** Agricultural systems remain quite varied, with plant- and animal-based systems, monocultures and mixed farming, plus newly emerging systems including organic, precision, and peri-urban approaches to production. Today, over a third of the world's land surface and ~3/4 of freshwater resources are devoted to agropastoral production {2.1.11}. Grazing occurs on ~50% of agricultural lands and ~70% of drylands {2.1.11}. About 25% of greenhouse gas (GHG) emissions come from land clearing, crop production, and fertilization, with animal-based food contributing 75% of it. Intensive agriculture has led to increases in food production at a cost of multiple regulating and non-tangible contributions from nature and even overall decreases in well-being in cases {2.1.11}. Small land holders (< 2 ha) contribute ~30% of global crop production and ~30% of the global food supply – using 24% of agricultural land and with the largest agrobiodiversity levels {2.1.11}. Their diverse agricultural systems, developed over centuries, have reduced negative impacts on nature, providing a wide range of material and regulating and non-material contributions, while generating the basis for sustainable agriculture intensification, soil management and integrated pest management {2.1.11}. Organic agriculture has developed rapidly, with variable outcomes: in general, it has contributed to higher biodiversity, improved soil or water quality, and nutritional values, although often at the expense of lowering yields and/or raising consumer prices {2.1.11}.

24 **Industrial roundwood harvests have risen, while bioenergy use rose dramatically in the rural areas of poorer regions, with some sustainable forest management (*well established*).** Reductions in forest cover during 1990 to 2015 totaled 290 million ha (~6%), although the areas of planted forests rose by 110 million ha (51%) {2.1.11}. Industrial roundwood made up half of the global harvest (3.9 billion m^3 in 2017), with fuelwood the other half {2.1.11}. Industrial harvest is falling in high income countries but rising in upper-middle and lower-middle income countries {2.1.11}. Global bioenergy uses almost tripled, largely in Africa, although bioenergy fell as a share – from 15% to 10% – with 30% of global fuelwood deemed unsustainable and over 200 million people facing rural fuelwood scarcities, mostly in South Asia and East Africa {2.1.11}. Sustainable forestry has been tried in many countries, over some time, including for forest certification, with some positive impacts upon forest cover and biodiversity, although mixed social impacts {2.1.11}.

25 **Harvesting wild plants and animals from land- and seascapes supports the livelihoods of a large share of the globe's population, raising sustainability concerns *(well established)*.** Over 350 million people – mostly lower-income households in Africa, Asia, Latin America – depend on non-timber forest products (NTFPs) for subsistence and income. Over six million tons of medium-to-large-sized mammals, birds, and reptiles are harvested in the tropics, annually, for bushmeat. Also, ~6 million wild ungulates are harvested in the Northern Hemisphere every year, by game hunters {2.1.11}. Evidence on sustainability is sparse, yet a well-managed harvesting of resources with strong local involvement could benefit both livelihoods and conservation {2.1.11}.

26 **Mining has risen dramatically, with big impacts on terrestrial biodiversity hotspots and global oceans, mostly in developing areas with weaker regulation *(established but incomplete)*.** Hundreds of mined products serve quite diverse purposes, globally, contributing more than 60% of 2014 GDP for 81 countries, with 17,000 large-scale sites in 171 countries. Most minerals are produced by large international corporations {2.1.11}. Still, small-scale mining is important in the livelihoods of many rural poor in the developing world – where many corporations have now located, given weaker environmental and social regulations (Africa is estimated to have 40% of global gold, 60% of cobalt, and 90% of platinum reserves) {2.1.9, 2.1.11}. Such impacts of mining are a growing concern, including per conflicts and illegality – although systematic quantitative data are unavailable {2.1.9, 2.1.11, 2.1.13}. Mining utilizes under 1% of global land but its negative impact on biodiversity, availability and quality of water, and human health may be larger than from agriculture {2.1.11}. Gold mining is of particular concern, given the rising demands and big impacts on biodiversity hotspots (despite protected areas) {2.1.11}. Ocean mining has been increasing, with ~6,500 offshore oil and gas installations, worldwide, in 53 countries (60% in the Gulf of Mexico) and possible expansion in the Artic and Antarctic regions as ice melts {2.1.11}.

27 Dams, roads, and cities have strong local negative impacts on nature, yet they also can have positive spillovers associated to increased efficiency and innovation (*well established*). While new infrastructure tends to have negative local consequences for nature, it can also have significant positive and negative spillovers {2.1.11}. The total number of dams has escalated in 50 years, with ~50,000 large dams (> 15 m height), and ~17 million reservoirs (> 0.01 ha) holding ~8,070 km^3 of water {2.1.11}. Urban area, while accounting less than 3% of the total land area, is rising faster than urban population and is associated with large effects beyond cities, which affect regional climates, hydrology and pollution {2.1.11}. Yet urban areas can excel in stewardship, e.g., raising flood resilience, reducing emissions, and constructing biodiversity friendly spaces {2.1.11}. New transport infrastructure tends to raise forest losses on frontiers, with direct negative impacts on biodiversity, plus exacerbate the environmental impacts of other developments, such as large mining operations {2.1.11}. Yet within more developed settings, shifts in transport costs can help forests {2.1.11}. Increasing human encroachment, land reclamation, and coastal development have strong impacts on coastal environments {2.1.11}. More and better planned infrastructure is found in higher income countries while fast, ill-planned expansion of infrastructure is found in rapidly growing urban and peri-urban settlements, especially in Africa and South and East Asia {2.1.11}.

28 Tourism has risen dramatically with huge impacts on nature overall, higher impacts for the higher-end options, and mixed outcomes from nature-based options (*well established*). Tourism grew dramatically in the last 20 years both domestically and internationally, especially from high and upper-middle income countries, with international travel levels tripling {2.1.11}. During 2009–2013, tourism's carbon footprint rose 40% to 4.5 Gt of carbon dioxide (8% of the total greenhouse gas emissions involved in transport and food consumption related to tourism) {2.1.11}. Most of those emissions are in, or from, high income countries. The impacts of a trip vary 1000-fold in terms of energy use, being higher for luxury accommodations and selected transportation types for the globally growing class of wealthy travelers {2.1.11}. The demand for nature-based or eco-tourism also has risen, with mixed effects on nature and societies {2.1.11}.

29 Both airborne and seaborne transportation of goods and people has risen dramatically, causing both increased pollution and a significant rise in invasive alien species (*well established*). Transport of goods and people has risen drastically over the last few decades, with the number of air flights doubling globally (1980–2010) and tripling for high income countries {2.1.11}. Seaborne carriage has doubled for oil, quadrupled for general cargo, and quintupled for grain and minerals over this period, while the voyage lengths have also increased {2.1.11}. The transport of goods and people have direct, indirect, and cumulative impacts upon nature including pollution (of air, water and soil), greenhouse gas emissions (contributing 15% of the global CO_2 emissions) and varied durable consequences along trade routes including introductions of invasive alien species {2.1.11}.

30 Restoration can offset current degradation levels, with varied intensities and outcomes, although global initiatives have focused mostly on our forests (*established but incomplete*). Restoration increasingly is required, given the ongoing degradation of various ecosystem types. It offers direct and indirect benefits through material, regulating and non-material NCP {2.1.11}. Approaches range from passive to active – with distinct costs, limitations, extents, and outcomes – though no global data are available on its current extent and outcomes {2.1.11}. One large-scale initiative is the Bonn Challenge aiming to restore 350 M ha of degraded forestland worldwide by 2030, yet no similar global challenges have been proposed for any non-forest ecosystems {2.1.11}.

31 Illegal extraction – including fishing, forestry and poaching – adds to unsustainability, yet is fostered by markets (local, global) and poor governance (*established but incomplete*). Illegal, unreported or unregulated (IUU) fishing made up 33% of the world's total catch in 2011, being highest off the coast of West Africa and in the Southwest Atlantic {2.1.11}. Illegal forestry supplies 10–15% of global timber, going up to 50% in some areas, worsening both revenues (for private or state owners) and livelihoods for poor rural inhabitants. Illegal pressures also increase the costs of trying sustainable forest management {2.1.11}. Illegal production of biofuels is large, especially for small, poor, informal actors in Africa {2.1.11}. Poaching is rising, pushing species (e.g., rhinos, tigers) toward extinction despite considerable international efforts {2.1.11}. Illegality is incentivized by high prices of species in demand and, for the low prices often received by the poor, driven by weak regulation and enforcement, with corruption and poor management {2.1.11}.

II-B. DIRECT DRIVERS – AGGREGATED IMPACTS OF ALL ACTIONS ON NATURE

32 The largest transformations in the last 30 years have been from increases in urban area, expansions of the areas fished, and the transformations of tropical forests (*well established*). Today, 75 per cent of the total land surface and 40 per cent of the ocean area are severely altered {2.1.12}. The total area of cities has doubled from 1992 to 2015, with the most severe impacts in tropical and subtropical savannas and grasslands {2.1.13}. Agriculture area in the tropics expanded mostly at the expense of tropical forests, with large expansions (~35 million ha) associated with cattle ranching in Latin America, linked to diets, and plantations, including for oil palm {2.1.13}. Land-cover changes have led to increasing fragmentation of the remaining forest as well {2.1.13}. Technological advance in agriculture, fisheries and aquaculture, and forestry has yielded at times irreversible shifts in ecosystems and in nature's contributions. These are exacerbated by greater livestock densities, changes in fire regimes, and intensifications leading to accelerated pollution of soils and water {2.1.13}. Soil degradation – including erosion, acidification, and salinity – has increased globally, although further systematic and reliable information will be required {2.1.13}.

33 **Demands for materials for nature have escalated, especially in developing countries and the Asia and the Pacific region, accounting for unprecedented global impacts *(well established)*.** The total demands for living and nonliving materials increased sixfold from 1970 to 2010, while the demand for materials used in construction and industry quadrupled during that time. The most drastic increases in demands for construction materials – on the order of ten times – occurred within developing countries and the Asia and the Pacific region. The extraction of living biomass from agriculture, forestry, fishing, hunting, and other activities has nearly tripled, globally – with the rapidly growing developing countries having the highest current levels for the rates of extraction for all living and nonliving materials {2.1.12, 2.1.14}.

34 **Pollution has been increasing at least as fast as total population, with key differences by region and by type of pollution – with more monitoring needed *(established but incomplete)*.** While quantitative assessment of pollution is limited in terms of the amount and quality of data in many countries, current data show pollution rising at least as fast as is the human population. Untreated urban sewage, industrial and agriculture run-offs, as well as oil spills, and dumping of toxic compounds, have had strong negative effects on freshwater and marine water quality {2.1.15}. Non-greenhouse gas atmospheric pollution, such particulate matter, is highest in countries with low or no regulation standards and poor enforcement, often at lower income. Fertilizer use rose fourfold in only 13 years, in Asia and the Pacific, and doubled in developing countries {2.1.11, 2.1.15}.

35 **Alien species increasingly are recorded across continents, although less in Africa, given variable rates of species 'invasibility' and monitoring capacity *(established but incomplete)*.** Current cumulative records of alien species are ~40 times larger in developed than in least developed countries. Though comparable across Europe and Central Asia, the Americas and Asia and the Pacific, they are ~4 times lower in Africa {2.1.12, 2.1.16}. This has resulted from increased trade and population densities but also large differences in detection capacities and 'invasibility' across alien species.

36 **Climate has changed since pre-industrial times due to anthropogenic activities and has influenced impacts, on nature and society, of many other critical drivers *(well established)*.** Anthropogenic activities – in particular those raising greenhouse gas emissions – are estimated to have caused approximately a 1.0°C warming by 2017, versus pre-industrial times, with ~0.2°C (±0.1°C) rises per decade. The fastest changes are observed in flat landscapes at higher latitudes {2.1.17}. The frequency and the magnitude of extreme weather events both have increased across the last five decades, while the global average sea level rose at a rate of over 3 mm yr^{-1} over the last decades {2.1.12, 2.1.17}. Greenhouse gas emissions per capita are highest for developed countries, though are decreasing there; they are followed by those in developing countries where they have increased by 10% since 1970. Decreases are associated to changes in behaviour, due to perceived threats, plus responses in governance and innovation – as well as some shifts in emissions to other countries {2.1.17}.

III. Development Pathways

Dominant development dynamics involved complex interactions across countries and regions, leading to inequalities in nature and trade-offs

37 **Rising interactions via global trade shifted consumption's footprints *(well established)*.** The consumption footprint per capita of each country, measured as the amount of land needed to support consumption, rises with per capita income or per capita GDP. Thus, it is far from equal. It rises even more rapidly for elements beyond the consuming country's borders that can reflect stronger governance of nature within the consuming countries. That affects nature more in low income countries with weaker governance {2.1.18}. Alternatively, production might shift to more efficient locations and reduce total degradation as efficient production lowers market incentives for supply. Strategies in international governance also affect nature beyond countries' borders. For instance, protected areas can block inefficient production in forest habitats in low income tropical countries that are highly prized, shifting production to less prized locations elsewhere. On net, though, trade-based degradation has flowed toward those countries with lower income.

38 **The trade-offs between economic growth and degradation have shifted *(well established)*.** Even for higher-income countries, earlier economic development during the last 50 years mostly occurred at the expense of local nature. When trade and governance increased imports

of nature from low income countries, economic aid (perhaps compensating global public goods as above) could provide those countries with local net benefits {2.1.2, 2.1.18}. In contrast, concentrating power in global supply chains lowers economic returns in lower-income countries from appropriations of nature – sometimes with net local environmental and economic costs. These interactions helped high income countries to protect their nature while continuing to have economic growth {2.1.2, 2.1.18}, although the relative rates of growth, based on such exchanges, depend on the bargaining power.

39 **Economic and environmental inequality evolved, across income levels (*well established*)**. Globally, GDP per capita has increased relatively steadily over time {2.1.2}. Increases have been unequal over space, however. Globally, economic inequalities have steadily increased (note that within countries, the evolutions of inequalities have been uneven, averaging out to little change). That in turn can shift bargaining power, yielding unequal divisions of the gains from interactions, though dynamics can include convergence, with more rapid GDP growth in emerging economies (more generally, developing countries are intermediate between the developed and least developed countries' pathways). Inequalities within and among countries can make collective actions (coordination, cooperation) that are needed for conserving and restoring nature's contributions even harder to achieve {2.1.2, 2.1.18}.

40 **Social instabilities linked to scarcities in nature are part of current and future threats to nature based upon economic, social, and geopolitical conflicts (*established but incomplete*)**. Conflicts result from interactions concerning availability and control over nature's contributions {2.1.18}. More than 2,500 conflicts over fossil fuels, water, food and land are currently occurring. Lower-income countries that tend to be rich in natural resources have experienced more conflict – exacerbating environmental degradation, lowering GDP growth, and raising migration {2.1.18}. Communities expelled from lands or threatened by degradation (e.g., deforestation, mining or the expansion of industrial logging) have been associated with related violence (e.g., ~1,000 activists and journalists killed during 2002 to 2013) {2.1.11, 2.1.18}. Armed conflicts have direct physical impacts on ecosystems, beyond their destabilizing effects on resource uses and productivity {2.1.18}. The ecosystems relatively untouched by human activities can be particularly vulnerable to intrusions of this type, because remote ecosystems with few humans have harbored illegal activities {2.1.11, 2.1.18}.

41 **Social-ecological dynamics yield balances and regime shifts (*established but incomplete*)**. Interactions among drivers can generate iterative dynamics that raise outcomes variability {2.1.18}. Some systems equilibrate, e.g., if scarcities are perceived then prices and governance initiatives may rise as responses, then recede {2.1.18}. Other systemic interactions have led to rapid changes and extreme outcomes including 'regime shifts' for ecosystem functions: marine hypoxic zones; species invasions; or desertification {2.1.18}. Some collapses have arisen in high income settings, as challenges for rulemaking and enforcement confounded local regulations, despite capacities. Some dysfunctions have resulted in conflicts, in and across societies, which extend dysfunction: e.g., food shortages due to climate shifts, and unequal access, have generated 'food riots' {2.1.18}. Serious conflicts and societal shifts have arisen within mining, water, biodiversity, and land – sometimes financed by resource extraction and exacerbating environmental degradation {2.1.18}.

42 **Dynamics include (nonlinear) recoveries to good balances (*established but incomplete*)**. Systemic interactions have led some settings towards a positive 'equilibrium', with a reduction of degradation or a restoration of nature {2.1.18}. For example: policies that affect a fishery stock by shifting some behaviours may 'tip' the setting into sustainable harvesting, in which individual actors shift into making choices consistent with stock preservation; or, conservation sometimes spreads if one group observes benefits to earlier adopters and, so, chooses to mimic their actions. Further, individual nations' participation in some global collective agreements has spread when payoffs from joining rise with the participation of other countries – so leadership matters {2.1.18}.

2.1.1 INTRODUCTION

The globe's diverse citizens strive to achieve a good quality of life, with diverse perspectives on what is needed to achieve that, as a result of varied relationships with each other and with nature. Nature supports all these individual and collective pursuits, through contributions detailed in this volume (see chapter 2.3): provisioning or material contributions, such as food and timber; regulating contributions, such as climate regulation and protection of soils; and cultural and non-material contributions, such as learning and inspiration. Meeting the individual and societal demands for nature has posed severe and heterogeneous challenges. Some groups still do not have their basic needs met from nature's contributions yet increasing demands upon nature are exceeding rates at which contributions can be sustained (IPBES, 2018b, 2018e, 2018c, 2018d). At current trends, we risk drastic degradation, with drops in contributions critical for societies and uneven distributions of losses.

Basic needs and luxuries depend on nature, i.e., on land, plants and animals, minerals, and water whose supplies depend upon myriad functions of ecosystems, such as nutrient cycling and water purification. How nature is manipulated, including within markets, depends upon socioeconomic factors: values, incomes, technologies and power (i.e., who determines which development ideas are implemented and how). Scarcities drive human responses, including governance institutions, from norms to national policies. Yet markets' prices often fail to reflect scarcities in nature, thus degradation remains invisible in local and global economic systems, for rural and urban settings. Likewise, individuals and society often fail to fully recognize and to incorporate the value from nature's contributions, despite their immense importance for multiple dimensions of well-being.

For this global assessment of nature, and its contributions to people, we are concerned with all of these pursuits. Every one of the Sustainable Development Goals (SDGs), for instance, is critical. Yet we focus on the consequences for nature from economic and social development trajectories, over the past 50 years, that centrally involve interactions across local, national and global scales. Those consequences, in turn, enable or constrain potential for future development, sustainable or otherwise. Our focus in this chapter is on understanding the indirect and direct drivers affecting past and present, and influencing possible trajectories for nature, and people, at different scales.

To broadly describe the interactions between society and nature that underpin trajectories within development, we analyze the evolution of different categories of drivers that affect nature and its contributions to people. First, we cover **indirect drivers**, i.e., factors behind human choices that affect nature. This starts with values, as goals affect choices. We next consider 'demographic' (population, migration, education) and then 'technological' (innovation) factors. Next come the 'economic' factors: structural transition, i.e., shifts across economic sectors such as agriculture, manufacturing, and services; concentrated production, i.e., shifts in output shares for big actors; and trade as well as financial flows that continue to increase within and across national borders.

Finally, we consider 'governance', an overarching sub-category of **indirect drivers** that includes all types of governance. They respond to scarcities in nature's capacity to generate contributions: scarcities increase the likelihoods of responses although many other factors also determine them.

Within governance, we distinguish different forms, while emphasizing their many interactions. We start with efforts by private actors within supply chains, e.g., the certification of production processes for environmentally beneficial features for which at least some consumers would pay. Moving outside markets, we consider coordination at local levels within community governance. We then consider the governance by formal states, i.e. policies from local scale to national scale, and their interaction with community governance which can either enhance or worsen outcomes. Finally, we consider coordination across governments – i.e., 'global community governance' – that must address challenges similar to those which face smaller-scale community governance.

We then move to the **direct drivers**, i.e., direct human influences upon nature – in seven sections. The first section (2.1.11) covers human actions, e.g., farming, fishing, logging, and mining, that respond to indirect drivers and directly affect nature. Interventions often aim to shift such actions, based on theory and evidence about dominant dynamics. Section 2.1.12 gives an overview of all the influences on nature from those actions for aggregate influences upon nature, which are detailed in the following sections These include land/seascape change (2.1.13), resource extraction (2.1.14), pollution (2.1.15), invasive alien species (2.1.16) and climate change (2.1.17). Both sections consider efforts to reduce degradation and recover nature, i.e., restoration efforts and outcomes.

Following chapter 1, our final section (2.1.18) "closes the loop". Direct drivers feed processes in nature that, in turn, feed into the process of co-production of all nature's contributions to people (NCP). In turn, NCP abundance and scarcities affect the quality of life of everyone within a society and, thereby, spur shifts in indirect drivers such as values, market prices and other institutions. Thus, we can work through cases of drivers' consequences coming around to shape drivers' evolutions. We consider the implications of such iterations for future (perhaps sustainable) development pathways.

Understanding development trajectories with global interconnections.

Intensified global interconnections have been a defining feature of the last 50 years. Any global perspective includes how regional, national, and subnational trajectories – for nature, economic development and governance – have interacted at a global level. Figures below articulate how as a consequence, the trajectories observed across the last 50 years, while related to each other, have differed considerably across space and time, e.g., as experienced by different groups of countries in terms of nature **(Figure 2.1.1)**, economic growth, and environmental governance **(Figures 2.1.2-2.1.3)**. The figures aim to illustrate how least developed, developing, and developed countries followed distinct but interconnected trajectories, given differing and interacting bundles of indirect and direct drivers in and across regions with cumulative and/or cascading effects over time. In many cases, varied trajectories are present in single countries. An example for forests, in **Box 2.1.1**, illustrates how various interconnections of multiple drivers across and within regions shaped forest landscapes.

Observed historical trajectories for important elements of nature can be summarized using a few possible steps: degradation to start, almost surely; then possibly also stabilization, and recovery **(Figure 2.1.1)**. The trajectories for different societies are not necessarily independent, however, and we explore how they could be the result of interacting trajectories of indirect and direct drivers – due to individuals' and societal choices. For instance, if one society recovered certain capacities of nature after degrading them (as is observed in various regions especially in the 'Global North'), how could that transition have occurred within a world in which other societies did not choose or were not able to reverse related negative trends within nature? Looking across 50 years, were the observed transitions simply independent choices by heterogeneous societies to regulate more, or invest more in sustainability, or consume less? Or did recoveries rely upon degradation in other countries? And, going forward, what are the implications of those interactions for trajectories?

Next, we wish to consider whether multiple dynamics could generate each trajectory in **Figure 2.1.1** because exactly how a country or region managed to stabilize or to improve elements of nature affects not only the sustainability of those changes but also the implied consequences for others. For instance, some societies enjoyed greater initial endowments of particular natural resources – such as minerals, land, climate, and ecosystem productivity on many dimensions (Scheffer *et al.*, 2017) – which in general could improve those trajectories.

However, natural wealth alone has proven not to be sufficient for ongoing positive trajectories, independent of society's institutions and choices. In fact, many distinct evolutions of different bundles of indirect drivers could affect nature similarly – i.e., generate the same trajectories in **Figure 2.1.1** – yet differ greatly in trade, governance,

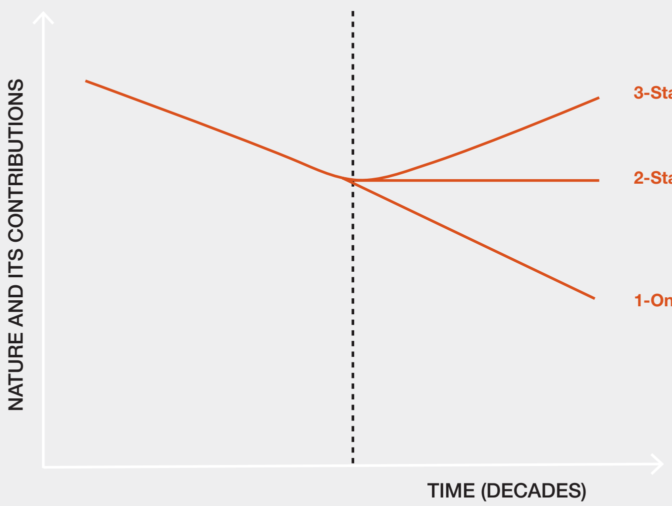


Figure 2 1 1 **Illustrative trajectories along differing development pathways for 'nature', i.e., its productive stocks or its capacity to generate valued contributions, at the time scale of decades.**

The first trajectory is ongoing degradation, the second is stabilization after degradation, and the third is not only stabilization but also a reversal or recovery. The vertical line is a point of transition, whose timing depends upon many factors, including scarcities in nature.

Box 2 1 1 Multiple dynamics driving forest cover can underlie stabilization or recovery.

Forests provide examples for such dynamics (IPBES, 2018a). Global forest cover has been close to stable in recent years, yet forest cover decreased in some regions while stabilizing or even recovering in others. Existing theories about processes underlying such trajectories (Meyfroidt *et al.*, 2018) propose dynamics that have similar forest trajectories but differ on other dimensions in **Figure 2.1.2**. Forest degradation often results from agricultural expansion, for which there are many examples, including within the tropics, where that remains a significant phenomenon (Barlow *et al.*, 2018; Curtis *et al.*, 2018; Hansen *et al.*, 2013). This is common enough that it could explain initial and continuing downward slopes within a version of **Figure 2.1.1** for forest.

'Forest transitions' (**Figure 2.1.1**, Trajectory #2/#3) were observed in Western Europe and North America (Mather & Needle, 1998; Rudel, 1998), then East and South Asia (Foster & Rosenzweig, 2003; Kauppi *et al.*, 2006), and parts of Latin America. Different dynamics underlying transitions have been highlighted in varied literatures (Caldas *et al.*, 2007; Geist *et al.*, 2006; Gutman *et al.*, 2004; Rindfuss *et al.*, 2004). We consider some below.

Intensification. For a fixed area, outputs can rise via changing knowledge and practices, inputs and tools to promote 'intensification' – such as double cropping or higher-yield crop varieties (Thaler, 2017). Incorporating trees is an agropastoral option which also aids biodiversity (Pagiola *et al.*, 2016; Perfecto & Vandermeer, 2010). If adoption of any of the above alternatives were to be universal, then forests might stabilize or even recover in all countries, while across-country inequality would depend upon biophysical and societal constraints on yield.

Transition to manufacturing/services. A distinct dynamic is sectoral transition from agriculture to manufacturing and services, within processes of both urban and industrial growth – often along with rural depopulation and a spatial contraction of increasingly intensive agricultural production. This may raise affluence and the demand for improving ecosystem health and ensuing regulating and cultural contributions (e.g., Mather & Needle, 1998; Rudel, 1998) that affect both governance and trade (see, e.g., Mather, 2007; Rudel *et al.*, 2005; Viña *et al.*, 2016).

Substitution by imports. Countries also have stabilized forest cover by importing wood or food, grown at the expense of forests elsewhere (Meyfroidt *et al.*, 2010). In this dynamic, recoveries rely on others' degradation. Some countries follow Trajectory #1, as still occurs in the tropics. With increasing global trade, sources of inequalities between countries include differences in who gained from these trades, given differences in power across firms and countries, including in abilities to increase value in forest and agricultural products through transformation processes.

economic outputs, and various inequalities. Further, within many of those dynamics, outcomes differ as a function of countries' development level (those additional dimensions plus broad differences across development levels motivate **Figure 2.1.2**).

Box 2.1.1 lists varied interconnections that shaped forest landscapes, both illustrating **Figure 2.1.1**'s trajectories, and their interconnections at the global level, and illustrating that there is a suite of different implications of the achievement of **Figure 2.1.1**'s trajectories. In and beyond forest cover, these differing and interrelated possible trajectories for nature involve some countries being able to 'transition' from the degradation of nature to a stabilization or a recovery within their borders, while others incur the costs of degradation. In other settings, the stabilization or the recovery of nature in one country is not dependent on degradation elsewhere, so reversal is possible for all.

Again, then, for forest cover, and beyond, the trajectories of countries can be highly contrasting (motivating **Figure 2.1.2**). In general, provisioning contributions from nature raised gross domestic product (GDP), even in per capita terms despite rising populations, during initial degradation of nature via transformations of ecosystems for agriculture (i.e., to the left of **Figure 2.1.2**'s transition). Further, between-country economic inequality rose – while falling or rising in different countries – since scales of economic activity differed. Output per unit of natural degradation also differed, as countries with higher income could combine more physical, financial, educational and social capital with their natural capital in production. They also could have had different past histories, e.g., longer periods of depending on nature beyond their borders, through colonization or trade. Thus, many countries' periods of early economic development had similar impacts on nature but differed in economic trajectories, including in trade and in (relatively rare) governance of nature.

Nonetheless, each trajectory involves particular trade-offs in meeting the society's diverse needs, through both production and conservation. Yet, since countries' trajectories are not independent, given rising global interconnections, which mechanisms or settings facilitate or drive transitions has significant implications for who reaps gains or bears the costs of degradation and recoveries. Some possible inequalities in trade-offs between gains and losses in nature and economic output, looking both within and across countries, are illustrated by contrasting trajectories in **Figure 2.1.3**.

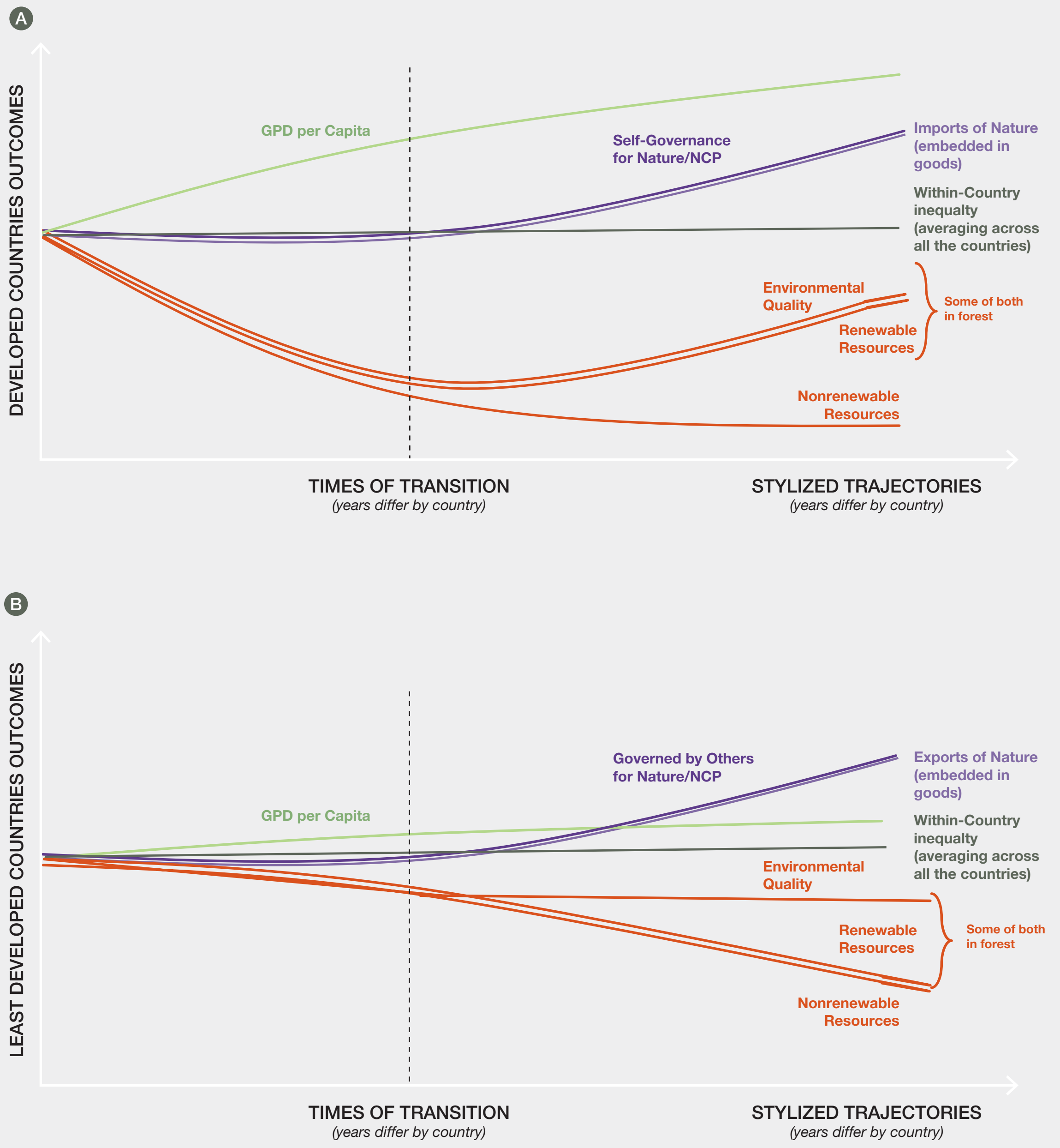


Figure 2 1 2 **Stylized sketches of average trajectories in developed countries outcomes A and least developed countries outcomes B.**

From bottom to top: quality of environment and natural resources ('renewable' like fish or trees, which regrow, or 'non-renewable' like oil or ores); institutional features of economies (i.e., trade) and societies (i.e., governance); gross domestic product (GDP) per capita; and inequality in GDP per capita. This figure builds upon **Figure 2.1.1**, with vertical lines indicating times for transitions that, in reality, happen at different times in different countries.

Consider, for instance, the degradation of nature as well as the other outcomes from expansion and intensification dynamics of economic activities. Regulations can limit the areas affected by those activities (e.g., agriculture), and a country also can invest to raise its outputs per unit area and, further, even to lower total 'environmental footprint' (e.g., abandon activities and reforest); which can produce the Self-Governing trajectory: recovery for nature, slower GDP growth **(Figure 2.1.3)**. Whether all this occurs depends on whether the society places a sufficiently high value on forest.

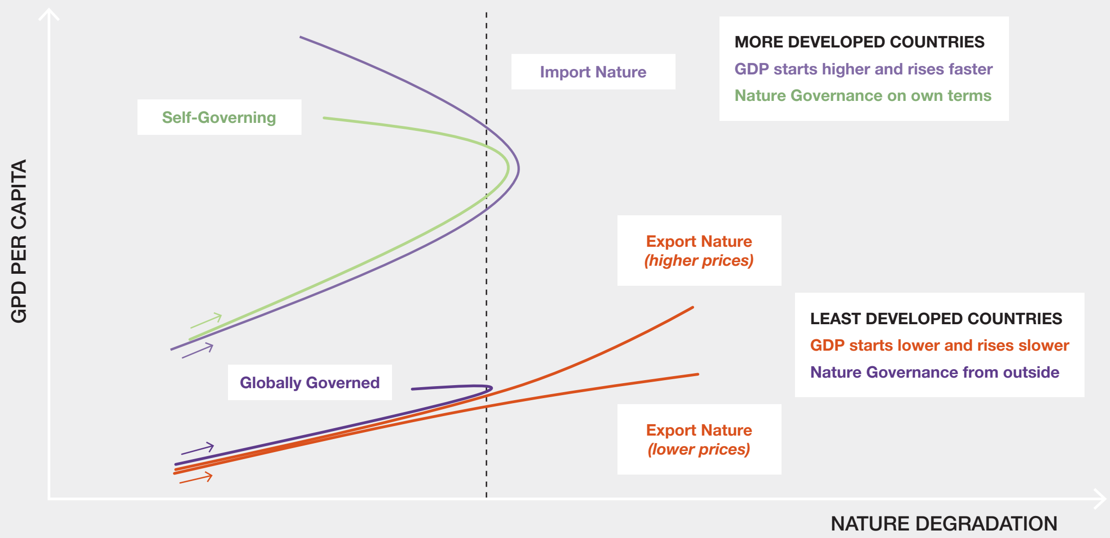


Figure 2 1 3 **Stylized sketches of cross-country interactions in trajectories for material contributions of nature.**

y-axis = GDP per capita and capacity for future material, regulating and non-material contributions, x-axis = nature. Imports and exports of nature are embodied in goods, e.g., water in food or trees in timber decrease for exporters and increase for importers. As in Figures 2.1.1 and 2.1.2, a vertical line indicates a point of possible societal transitions.

Instead, developed countries may conserve nature (e.g., forest cover) by importing forest and agricultural goods from least developed countries, albeit at the expense of nature for the exporters. For importers, an 'Import Nature' trajectory may be better than meeting needs by self-governing, though whether this occurs depends on whether exporters put a sufficiently low value on forests. The trade-offs depend on export prices, as illustrated in two Export Nature trajectories **(Figure 2.1.3)**.

Alternatively, developed countries may advocate – and cover the costs of – nature governance in least developed countries such as strict protected areas that make some local uses of forest illegal. That may provide global public goods – yet sometimes by imposing net costs on the local actors. A rise in nature could raise welfare for developed countries, yet lower GDP for least developed countries, if the latter cannot shift into other activities that support economies (Globally Governed trajectory). This motivates a quest for actions to help nature and local economies. For instance, forests might also increase if enforced protected areas flanked new railway links that facilitated urban growth.

2.1.2 PAST TRAJECTORIES, THEIR TRADE-OFFS AND INEQUALITIES

2.1.2.1 Maintain nature or meet society's many and diverse short-run goals?

Compared with pre-1980 realities, the world has changed rapidly **(Figure 2.1.4)**. Population, urban areas and international migration have risen greatly. Overall, quality of life has improved, in the senses of, e.g., lower child mortality, or higher caloric intake, and varied summaries such as the Human Development Index. Economic development generally has advanced, in terms of per capita GDP and per capita consumption, while the value of merchandise being exported has also increased. Yet, these improvements have come at a real cost: increasing impact upon nature. Since 1980, food production systems have intensified and, although the overall areas covered by cities and agriculture have not drastically increased, more fertilizer and pesticides are being used while total pollution (including greenhouse gas emissions), the number of invasive alien species, and temperature anomalies are increasing, and biodiversity intactness is decreasing (see chapter 2.2 for more on this variable) – despite increasing efforts to protect key

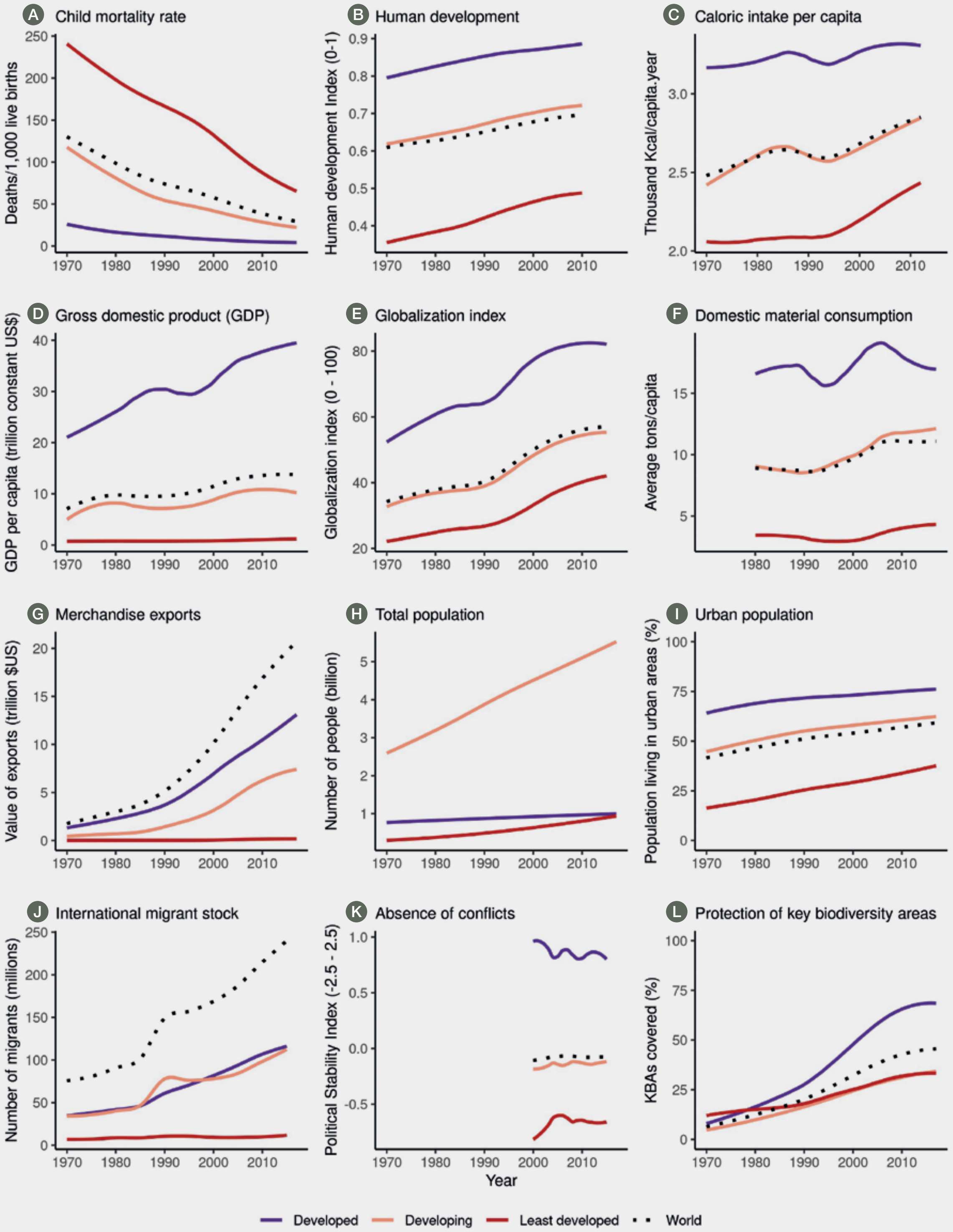


Figure 2 1 4 **Trends in indirect drivers for countries with different development levels.**

The data shown are trends, per country, averaged (A, B, C, D, E, F, H, I, and K) or totaled (G, J) for each of the three UN development categories: developed, developing, and least developed. Panels shown are: A **Child mortality rate:** Mortality rate, under-5 (per 1,000 live births); B **Human Development Index:** a summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable and have a decent standard of living; C **Calorie intake:** Kilocalories consumed per person per day; D **GDP per capita** (gross domestic product divided by midyear population) in constant 2010 U.S. dollars; E **Globalization index:** The KOF Globalization Index measures the

economic, social and political dimensions of globalization; F **Domestic material consumption per capita:** all materials used by the economy, either extracted from the domestic territory or imported from other countries; G **Merchandise exports:** value of goods provided to the rest of the world per country valued in current U.S. dollars; H **Total population**; I **Proportion of urban population:** Proportion of the total population that is urban, which refers to people living in urban areas; J **International Migrant Stock:** the number of people born in a country other than that in which they live (includes refugees); K **Absence of conflict as an indicator of political stability:** Index that measures perceptions of the likelihood that the government will be destabilized or overthrown by unconstitutional or violent means, including politically-motivated violence as well as terrorism; L **Protection of key biodiversity areas (KBA):** measures progress towards protecting the most important sites for biodiversity in % of such sites per country (including Alliance for Zero Extinction sites).
Sources: BirdLife International (2018); FAO (2016a); KOF Swiss Economic Institute (2018); UNDP (2016b); UNEP-WCMC & IUCN (2018); World Bank (2018l, 2018i, 2018q, 2018k, 2018n); WU & Dittrich (2014).

biodiversity areas (KBAs). These global patterns will be described in detail in each of the sections of this chapter.

The trends differ widely, though, across countries, global regions, and regions within countries. To highlight some differences, we use a typology that divides all countries into three development level categories **(Figure 2.1.4)**: developed, developing, and least developed, based on Gross Domestic Product (GDP)[1]. We also use the four World Bank categories of income: lower, lower-middle, upper-middle and high income (World Bank, 2018r), that can be aggregated (lower-middle and upper-middle into middle) or disaggregated (high income OECD and high income oil and high income other) as needed (Figure S2). Additionally, we refer to the IPBES regions (Figure S2): Africa, Americas, Europe and Central Asia, Asia and the Pacific (see Supplementary Materials: Table 2 for a comparison of typologies).

2.1.2.2 Inequalities

2.1.2.2.1 Poverty and inequalities with respect to basic needs

There have been some marked advances in terms of poverty reduction over the past few decades (Figure S5), though many people around the world still remain in poverty. Per the "international poverty line" established by the World Bank in 2008, equivalent to a daily income below $1.90 US dollars/person (in 2015 prices) (Ravallion *et al.*, 2008), ~1.2 billion people still live in poverty (UN, 2016a). According to the Multidimensional Poverty Index (MPI), introduced in 2010 in the Human Development Report (UNDP) using metrics for health, education, and standard of living, still ~1.5 billion people are living in extreme poverty.

Further, even while overall income has risen on average to above the international poverty line, clearly many other basic needs have not been met, despite significant global stresses on nature. Globally, food security (i.e., security in food supply, with elimination of caloric and nutritional deficiencies) has been increasing but remains low within least developed countries. Currently, despite average gains over time at the global level, close to 860 million people still suffer severe food insecurity across the globe, of which 48% are in Africa (particularly in sub-Saharan Africa) and 45% in Latin America (Figure S3) (WFP, 2017). Conflicts, refugee crises, droughts, floods, pandemics, and inadequate social institutions all have contributed to shortfalls both in aggregate food production, or food availability, and in the effective food supply, with 37 countries (28 in Africa) having received emergency food aid in 2016 (WFP, 2017).

In addition, while the child mortality rate – largely associated with a lack of water sanitation and food deficiencies – has decreased overall, this threat remains prevalent in low income countries, in which as many as 10% of the children born alive die before age 5 (World Bank, 2018l). Regionally, Africa and the Americas show highest mortality (Figure S3). While access to improved water resources has increased, on average, 40% of the world's population still is lacking access to safe drinking water, most of them in least developed countries, especially within sub-Saharan Africa (WHO & UNICEF, 2017). Furthermore, almost all maternal deaths during childbirth (99%) occur in developing countries, over half in sub-Saharan Africa (Wang *et al.*, 2011), as a result of water scarcity, poor management, and governance failures.

In terms of broader measures of well-being, the Human Development Index (HDI) that includes income, health (life expectancy at birth), and education (average number of years of schooling) (UN, 2016a) also illustrates great contrasts across the planet. Least developed and developing countries have much lower HDI values than do the developed countries (**Figure 2.1.4**; UNDP, 2016a). Africa has the lowest HDI values among IPBES regions, followed by Asia (Figure S3). Across regions, Indigenous Peoples and Local Communities (IPLCs) are among the poorest groups, by income but also in access to basic needs, services, and opportunities (Hall & Patrinos, 2012).

Countries differ in many other well-being metrics too (**Figure 2.1.4**, Figure S4), such as material conditions for life – frequently assessed from an economic perspective with economic indicators (see section 2.1.3). Higher-income countries rank higher for indicators associated with societal

1. https://www.un.org/en/development/desa/policy/wesp/wesp_current/2014wesp_country_classification.pdf

development and for sustainability (Figure S4) (Eira *et al.*, 2013; Inuit Circumpolar Council, 2015; Raymond-Yakoubian & Angnaboogok, 2017), including for various indicators of the options citizens have, also called 'freedoms', that are included in the World Happiness Index (WHI, 2017) (Figure S4). These countries also have better conditions than low income countries for access, equality, tolerance, and inclusion of minorities, as shown by the Social Progress Index (SPI, 2017) (Figure S4). With respect to metrics for the management of ecosystem services and environmental policies such as Environmental Performance Index (EPI, 2018), low income countries rank lower. Yet they rank higher in terms of indicators for diversity, environmental degradation, and ecological footprint, including consumption of renewable water resources. Low income countries exhibit higher rankings in the Environmental Component of the Social Sustainability Index (SSI.EV; Figure S4) which includes linguistic diversity (Maffi, 2005), cultural identity, and the retention over time of indigenous ecological knowledge as well as practices (Sterling *et al.*, 2017).

2.1.2.2.2 Inequalities in Income

Economic inequality across all countries has been rising since 1820 (Bourguignon & Morrisson, 2002; World Bank, 2018r), and also has escalated since 1980 (**Figure 2.1.4**; Figure S2; Figure S3; Figure S5; World Bank, 2018o), with the highest-income countries increasing their incomes faster (OECD, 2015). In 2017, the GDP per capita was nearly four times higher in developed than in developing countries and nearly 34 times higher than in least developed countries (**Figure 2.1.4**; World Bank, 2018i). In terms of growth, GDP per capita is rising fastest for developed and developing countries, but slower in least developed countries, making the gap among these particular groups larger every year.

Within-country inequality also shifted over time in many countries. However, the changes went in both positive and negative directions, and so on average, within-country inequality remained fairly constant (Bourguignon & Morrisson, 2002; World Bank, 2018o). Still, quite a few countries experienced rising within-country income inequality, as expressed by metrics such as the Gini coefficient (Figure S5) or the Palma ratio (Palma, 2006), with cases in which lower incomes fell while higher incomes rose – particularly in the Americas and Africa.

2.1.2.2.3 Lifestyles and Inequalities in Consumption

Consumption too has been escalating, across the last few decades, albeit with differences among countries and global regions. Energy consumption has been rising since the industrial revolution. Wood and oil from whales were replaced in the early 1900s by coal, petroleum and natural gas (Smil, 2004). By the middle of the 20th Century, the "Green Revolution" boosted agricultural yields through the application of fertilizers, pesticides, fungicides and herbicides, together with irrigation, all of which increased energy demands (Dzioubinski & Chipman, 1999). Total energy use has doubled in the last 40 years (World Bank, 2018g) (Figure S6), while substantial transitions to modern gridded clean fuels occurred between 1990 and 2010 (Pachauri *et al.*, 2012), allowing ~1.7 billion people access to electricity and about ~1.6 billion people access to non-solid fuels for household cooking. The greatest increases have occurred in middle income countries, while low income countries exhibited lower increases (Figure S6; World Bank, 2018a) with real variations in rates of technological development and in the initial endowments of energy resources (Burke, 2010; Toman & Jemelkova, 2017). For instance, high income non-oil-producing countries have been gradually reducing their use of fossil fuels and increasing the use of nuclear and other non-fossil-fuel sources (Figure S7). Among the highest energy consumers, in total as well as per capita, are high income countries where intensive agriculture is more prevalent (Figure S9).

Global patterns of food consumption have also changed over the past fifty years, with important differences by country (Figure S6). As nations urbanize, urban dwellers get wealthier, food supplies increase, and eating habits change. Diets are rising in refined carbohydrates, added sugars, fats, and animal-based foods (e.g., meats, dairy) but falling in pulses, vegetables, coarse grains, fruits, complex carbohydrates and fiber, in tandem with the diversity of food sources (Keats & Wiggins, 2014; Khoury *et al.*, 2014; Popkin *et al.*, 2012; Tilman & Clark, 2014). Again, the variations across regions are significant. From 1970 to 2015, global average caloric intake per capita rose by 15% – yet developed countries have the highest levels **(Figure 2.1.4)**, particularly in Europe (Figure S3), while the lowest levels are found in least developed countries **(Figure 2.1.4)**, particularly in sub-Saharan Africa (Figure S3). Likewise, by 2009 while the average per capita consumption of protein exceeded the average estimated daily requirements in all the regions of the globe, it is the highest in high income countries (FAO, 2011b, 2016a; Paul, 1989; Walpole *et al.*, 2012).

With those changes in diet, the number of obese and overweight people has grown (Figure S6), to 2.1 billion in 2013 (Ng *et al.*, 2014). This too differs by region, with six times more obese people in high income than low income countries today (Figure S6). Furthermore, there are large variations across regions in the amount of fats (e.g., fats in foods and oils) for human consumption. The lowest quantities consumed are in Africa, while the highest are in parts of North America and Europe. Both the quantities and qualities (animal-based versus vegetable oils) of fats are key features of the nutritional transitions in national diets (Ranganathan *et al.*, 2016). Fast-food options are rising in low income countries, as exemplified by the higher numbers of chain restaurants (e.g., McDonald's restaurants[2]).

New 'needs' have also emerged with economic development. For instance, after mobile phones first became accessible, their number quickly "exploded" to one for every five people in the world (Figure S6). In addition to providing useful services, phones cause important environmental impacts associated with mining of precious metals for components and with both the manufacture of electronics and their careless disposal (Babu *et al.*, 2007; Fehske *et al.*, 2011; Wanger, 2011; Widmer *et al.*, 2005).

2.1.2.2.4 Inequalities in Environmental Footprints

With changes in lifestyle, per capita demand for natural resources has increased – unevenly (**Figure 2.1.4**, Figure S1). For instance, domestic material consumption (DMC) – the total amount of material directly used in an economy, including domestic extraction and imports (Wiedmann *et al.*, 2015; WU, 2017) varies greatly. DMC per capita is ~5 times larger in high income countries than low income. As DMC per capita rose by 15% globally since 1980 (18% since 1970), the largest increases are in developing countries (73% since 1970), followed by least developed (18% since 1970; **Figure 2.1.4**). By IPBES region, since 1980, DMC rose most in Asia and the Pacific (20%), followed by Africa (18%), and rose least in Europe and Central Asia (7%) (Figure S3).

Such demands upon nature scale with both the total population and demand per person. As such, since 1970, global material consumption has risen over 1.4 times faster than has total population (**Figure 2.1.4**, Figure S1). With every 10% increase in GDP, the average material footprint of nations – raw material extraction in the final demand of an economy – has risen by 6% (Wiedmann *et al.*, 2015; WU, 2017). Once again, growth rates for absolute and for per capita material consumption are unequal. For example, from 1980 to 2008 they increased in all regions except Central Asia (due to the collapse of the former Soviet Union) and most rapidly in Northeast Asia (Wiedmann *et al.*, 2015; WU, 2017). The global amount of material extraction was approximately 70 billion tons in 2008 (Wiedmann *et al.*, 2015; WU, 2017). Asia has the highest material extraction of all the regions, while 2008's per capita consumption in North America was ten times higher, at 30 to 35 tons of raw materials, than in Central Africa (Figure S18). Total material extraction (living and nonliving) in developing countries is rising the fastest, due to rapid increases in total population and GDP and DMC per capita (**Figure 2.1.12**, Figure S17, Figure S18, Figure S25).

All of this has impacts upon ecosystems. Estimates of ecological footprints, based on demands for both material and regulating contributions to people from nature, suggest sustained increases of footprints that are beyond the biological capacity to supply them (Borucke *et al.*, 2013; Galli *et al.*, 2016, 2014; Lazarus *et al.*, 2015; Lin *et al.*, 2015; Wackernagel *et al.*, 2014). This is especially true for the developing countries that are growing fastest in people, per capita demand, and globalization **(Figure 2.1.4)**.

Critically, environmental footprints of country consumption increasingly stretch beyond borders (as discussed in the introduction, see **Figures 2.1.2 and 2.1.3**). The world is ever more global, in economic, social, and political terms (Figure S1). Globalization metrics are highest for developed countries and lowest for least developed countries **(Figure 2.1.4)**. Such indices of increased resource flows include a 12-fold rise in the value of exports from 1970 to 2017, with fastest increases in developing countries (20-fold), followed by least developed ones (15-fold) **(Figure 2.1.4)**. Footprints associated with exports can be larger than is indicated by these trade values, though, because the usage of resources is, on average, larger than physical quantities of traded goods (Wiedmann *et al.*, 2015).

2.1.2.2.5 Inequalities in Social, Environmental, and Historical Constraints

Differences in current conditions and trends among countries are associated partly with different natural endowments. High income OECD countries and upper-middle income countries have the largest fractions of renewable freshwater resources and agricultural lands, for instance, while oil-producing high income countries have the smallest such fractions (Figure S7), although the largest for nonrenewable resources (e.g., petroleum, natural gas). Forest cover is similar for countries with rather different income levels, except for oil-producing countries that have little (S7). Globally, natural assets represent about one tenth of total wealth, with produced capital three times and human capital six times as large. Yet for some countries with lower income levels, the natural capital constitutes most of their wealth (World Bank, 2018o). The contribution of natural capital to total wealth for high income countries is relatively small, roughly half the magnitude of the shares for low income countries (Lange *et al.*, 2018a). Thus, degradation of nature should have the strongest detrimental impacts on low income countries' future economic development.

Beyond the roles natural conditions play in divergent development pathways among countries – which are debated (Diamond, 1997; Gallup *et al.*, 1999) – countries also differ in institutions, e.g., in governance, culture, religion, philosophies, and past development. The colonial period was characterized by natural resource flows from the South to the North that often were linked with

2. https://stage-corporate.mcdonalds.com/content/dam/gwscorp/investor-relations-content/supplemental-information/2016%20Restaurants%20by%20Country.pdf

ecological damage and social oppression (Goeminne & Paredis, 2010; Nagendra, 2018). As a result, tropical civilizations whose total wealth was closer to their European counterparts in the precolonial era are now far poorer (Acemoglu *et al.*, 2005). Patterns of poverty in the tropics have been linked to a variety of institutions, such as some arrangements that enable inclusive economic growth that lowers poverty (Acemoglu *et al.*, 2001; Easterly & Levine, 2003; Rodrik *et al.*, 2004). The current patterns of poverty and the environmental conditions in the Americas, Asia and the Pacific, and Africa are still strongly influenced by the pervasive experience of past colonialism (16th to 19th centuries). Its continuing influences upon resource flows and trade arrangements contribute to persistent social inequality as well as weak governance institutions which perpetuate inequalities (IPBES, 2018b).

For instance, most economic growth in the last 50 years occurred in countries not experiencing civil conflict and with strong state institutions. Additionally, 70% of today's poor live in "fragile states" with cycles of violence, weak institutions, inequality, and low growth. All are obstacles to overcoming poverty (Sachs, 2005; Smith, 2007; World Bank, 2015a). Developed countries are more politically stable **(Figure 2.1.4)**, e.g., with European countries more stable than African (Figure S3).

All these inequalities have important societal and environmental consequences – for instance, differential conservation practices, depending on governance contexts. Inequality is associated with less protected land for relatively democratic countries, yet the reverse is true for relatively undemocratic countries (Kashwan, 2017). Some suggest nonlinear linkages between inequality and both economic and environmental outcomes (Dorling, 2010, 2012; Holland *et al.*, 2009; Mikkelson *et al.*, 2007). Equality has generally facilitated collective efforts to protect natural resources under common and public ownership or control (Baland & Platteau, 1999, 2007; Bromley & Feeny, 1992; Colchester, 1994; Dayton-Johnson & Bardhan, 2002; Itaya *et al.*, 1997; Ostrom, 2015; Ostrom *et al.*, 1999; Scruggs, 1998; Templet, 1995). Inequality may yield social and environmental vulnerabilities, including through the distribution of risk (Bolin & Kurtz, 2018). Inequality may also lead to conflict and, if both become self-sustaining by limiting opportunities and mobility – yielding hopelessness and a lack of a vision – that can fundamentally undermine the motivation to invest in nature for sustainability (Stiglitz, 2013; Wilkinson & Pickett, 2010).

2.1.3 INDIRECT DRIVERS: VALUES

2.1.3.1 Different social groups hold different values

The different values people hold concerning nature, nature's contributions to people, and their relationship to the quality of life affect people's attitudes toward nature and, thus, the policies, norms, and technologies which modulate people's interactions with nature. Values encompass principles or moral judgments that can lead to responsibility concerning, and stewardship towards, nature. They also encompass varied views about the importance or significance of something or a particular course of action. For instance, as highlighted within 'the water-diamond paradox', even though water is necessary for life, while diamonds clearly are not at all, the market prices for diamonds usually are far higher due to (at times intentional) market scarcities (Chan *et al.*, 2016; IPBES, 2015; Pascual *et al.*, 2017a; see chapter 1).

Values concerning nature can be relational, instrumental or intrinsic (chapter 1). Individuals and social groups who hold in high regard their relationships with nature often hold moral principles for living in harmony with nature. Such relational values are central for Indigenous cultures in many parts of the world. This is the case, for instance, of the Eeyouch of the Eastern Subarctic in Canada, who traditionally view humans, other animals, plants, some aspects of the natural world, and spiritual beings as all having conscious agency in a world that is dependent on relationships and on an ethic of mutual respect (Berkes, 2012; Descola, 2013; Motte-Florac *et al.*, 2012; Pascual *et al.*, 2017a). Also, some groups in the Tibetan plateau hold that intangible and mythical creatures or deities inhabit soils, water, air, rocks and mountains, and have different qualities and identities with whom humans need to find a balanced mode of interaction (Dorje, 2011). Aymara and Quechua communities in the Andes, as groups elsewhere using this or other terms, conceptualize Mother Earth as a self-regulatory organism representing the totality of time and space and integrating the many relationships among all the living beings. Such conceptualization is used by many Indigenous organizations to re-establish cultural links to ancestral practices and to contest forms of environmental degradation that are imposed on them (Medina, 2006, 2010; Ogutu, 1992; Posey, 1999; Rist, 2002). Relational views such as these examples support approaches to governance that reaffirm important points of interconnection and virtues (e.g., respect, humility, gratitude) and often lead to self-imposed restrictions on use of nature (Mosha, 1999; Spiller *et al.*, 2011; Verbos & Humphries, 2014).

Instrumental values, in contrast, reflect the importance of an entity in terms of its contribution to an end, or its utility. Entities can provide instrumental value for consumptive (e.g., use of water, energy, biomass, food) and nonconsumptive (e.g., nutrient cycling) uses. Utilitarian paradigms viewing nature as a resource for economic development have intensified over the last centuries, especially in industrialized regions. In this anthropocentric, materialist worldview nature is seen as a pool of material goods and energies to be mastered and employed (Merchant, 1980; Nash, 1989; Pepper, 1996; Plumwood, 1991), supporting the extraction of biodiversity and resources (Dietz & Engels, 2017) and both substitutability and discounting perspectives. Substitutability implies that ecosystems or their functions could be lost as long as their contributions to quality of life are provided in other ways (Traeger, 2011). Discounting gives less importance in decisions to future benefits or costs (Dobson, 1999; Padilla, 2002) – following the assumption that future generations will be better off (much as current generations are better off than the past (above)).

In practice, values can be simultaneously instrumental and relational. Many Indigenous Peoples and Local Communities in varied rural settings, for instance – indeed across the IPBES regions – relate to nature with deep respect not only due to their conceptualizations of key relational values but also because their livelihoods depend upon the food and other materials that nature provides.

Intrinsic values are an inherent property of the entity (e.g., an organism), not ascribed by external valuing agents (such as human beings). Because of this independence from humans' experiences, intrinsic values are beyond the scope of anthropocentric valuation approaches (Díaz *et al.*, 2015). Intrinsic values can be particularly relevant in nature for non-human and even nonliving entities (Krebs, 1999). In the face of environmental degradation, environmental movements in the 1970s advocated for the intrinsic value of natural entities (Hay, 2002), regardless of their usefulness to humans. These included sentient animals (Singer, 1975), all living beings (Taylor, 1981) or ecosystems with living and nonliving components (Devall & Sessions, 1985). Intrinsic values have been presented as a basis for laws and regulations or other governance to implement conservation agendas that minimize humans' interactions with nature (Purser & Park, 1995) while ensuring the well-being of future human generations by maintaining nature's contributions to people (Mace, 2014). Some argue that the intrinsic value of non-human entities and its implications for biodiversity conservation could be considered as part of a wide instrumental perspective (Justus *et al.*, 2009; Maguire & Justus, 2008).

Nature is also valued today for its contributions into the future (Faith, 2016; UNEP, 2015), from a number of perspectives. Bequest values consider present-day satisfaction of protecting nature for future generations, for instance, involving a principle of intergenerational equity. Insurance values pertain to resilience, in the face of change, while option values facing uncertainty focus on retaining the potential to access nature's benefits in future (Gómez-Baggethun *et al.*, 2014).

Access to food, water, shelter, health, education, good social relationships, livelihoods, security, equality, identity, prosperity, spirituality, as well as freedoms of choice, action and participation, are valued in different ways by people in a society and across different societies (Díaz *et al.*, 2015). Some of these values may be expressed through the use of a standard of exchange used by a community, such as money. Monetary value is considered a proxy for how people may perceive the worth of an entity. Multiple considerations influence the estimation of an entity's monetary value – or the amount that people are willing to pay – which complicates the identification of its full significance. Due to the diverse ways of conceiving and experiencing the relationships between humans and the rest of nature, people also often value nature and nature's contributions to people, including many ecosystem services, in ways that are incompatible with the reasoning in monetary exchanges (Pascual *et al.*, 2017b; UNEP, 2015).

2.1.3.2 Values of nature are rapidly changing

The values at the core of individual and social priorities and behaviours also can evolve over time, informed by awareness, experience, culture and society. Pressures associated with globalization, climate change, and population migration over the last century have been catalysts for social and cultural changes – including changes in the human perceptions of and relationships with nature. While urbanization may separate people from nature, there is a trend towards greater awareness of the importance of nature to human well-being in the scientific community and across society.

Long-standing values held by communities with strong ties to the land are increasingly disrupted, however, by economic globalization (Beng-Huat, 1998; Brosi *et al.*, 2007; Jameson & Miyoshi, 1998). Varied global influences can challenge local practices, including in the implementation of conservation. Local conceptualizations of conservation may differ from external conservation paradigms (Miura, 2005), although perhaps even more from consumptive views on exploiting remote ecosystems. Changes in values and lifestyle include the abandonment of indigenous and local knowledge, and traditional practices (Halmy, 2016), the erosion of traditional knowledge (Youn, 2009), and changes in institutions and community organizations (Mburu

& Kaguna, 2016; Ole Kaunga, 2017), as documented by IPBES assessments (IPBES, 2018b).

Migration, domestic and international, can disrupt relationships between communities and lands if arriving attitudes are not adapted to local socioecological conditions. Migration (resulting from conflict, lack of livelihood, urbanization, industrialization of agriculture, and changes in climate, among other reasons) can lead to local and also global losses of local environmental knowledge, governance and management practices that sustained local livelihoods (Merino, 2012; Robson & Lichtenstein, 2013). Significant numbers of people changing locations has driven changes in the worldviews, values, and practices of populations that migrate as well as those that receive them.

Climate change itself can also lead to changes in practices and the values associated with them (beyond effects through migration). For instance, both farmers and fishermen have been forced to shift daily and seasonal practices that affect not only their livelihood outcomes but also their long-standing senses of place, community structure, and cultural tradition (Breslow *et al.*, 2014).

A new ethic regarding nature has been called 'environmental activism' to explicitly challenge the dominance of the instrumental values (Callicott, 1989; Dunlap & Van Liere, 1978; Guthrie, 1971; Leach *et al.*, 1999; Leopold, 2014; Levins *et al.*, 1998; Meadows *et al.*, 1972; Naess, 1973). Recent examples include Pope Francis' encyclical address (2015), reassessing Christianity's vision of humanity's relation with Earth (Buck, 2016; Marshall, 2009). Relational values also enter into conservation dialogues (Chan *et al.*, 2016; Mace, 2014). More holistic approaches to sustainable use of nature by humans inspired in part from indigenous worldviews are stated in international agendas, e.g., living in harmony with nature is a principle of the Rio 1992 "Summit of the Earth" (Mebratu, 1998; UN, 1992) and Rio 2012 Conference on Sustainable Development (UN, 2012) and the vision of the Convention on Biological Diversity up to 2050. An International Day of Mother Earth is recognized in the Rio+20 "The future we want" document, linked to rights of nature (UN, 2009, 2012). Recognition of Mother Earth appears in recent climate change agreements (UNFCCC, 2015), in the Convention on Biological Diversity (CBD, 2014) and in the United Nations Environment Assembly of the United Nations Environment Programme (UNEA, 2014).

More generally, Indigenous groups are actively trying to protect their rights while strengthening the recognition of the legitimacy of their relational worldviews and related governance practices in the face of economic, political, social and environmental pressures (Baer, 2014; Blaser *et al.*, 2004). For instance, viewing nature as part of social life, not property to exploit, is suggested by the inclusion of intrinsic rights of the natural world in the constitutions of Bolivia and Ecuador (Lalander, 2015). Yet placing the rights of nature on par with those of Indigenous communities may support or undermine indigenous control and raise questions about how rights are linked with responsibilities. In Bolivia, for instance, rights of nature have been given equal standing to the rights of ethnic groups, while in New Zealand, some native (Māori) communities have successfully fought to gain political and legal power over land-use planning (Menzies & Ruru, 2011) in ways that lead to new laws that recognize the spiritual connection of an Iwi (tribe) to their ancestral place and the legal personality of national parks and rivers (Salmond, 2014).

Views of what constitutes a good quality of life are also changing. A vision welfare based upon economic development and material well-being prevailed in academic literature until the 1980s (Agarwala *et al.*, 2014), yet concepts of well-being have integrated additional dimensions and focused more on experiences of people (Gasper, 2004; King *et al.*, 2014; McGregor *et al.*, 2015) and include their capacities and connections with nature (Sterling *et al.*, 2017), together with education and health, knowledge and skills, happiness and satisfaction. Equity, justice, security and resilience lenses are also increasingly being integrated in definitions of well-being, alongside the recognition of different types of knowledge about life and cultural identities (Sterling *et al.*, 2017). Evolutions of values can have important consequences for nature and its contributions, modifying not only material consumption patterns and but also governance.

2.1.4 INDIRECT DRIVERS: DEMOGRAPHIC

2.1.4.1 Population dynamics

The world's population has doubled over the last 50 years (**Figure 2.1.4**; Figure S1), and is still growing, although the growth rate has peaked (Roser *et al.*, 2017). There are over 7 billion humans today (PRB, 2014). Important reductions in growth rates have been observed in developed countries, while the fastest increases are in the least developed countries **(Figure 2.1.4)**, and in Asia and the Pacific (Figure S3). These differences in growth rates are consistent with a 'demographic transition': population growth rates increase as child mortality decreases, leading to increased life expectancy; then fertility and growth decrease, leading to falling population growth rates, as has already been observed within some regions (Fogel, 1986; Hirschman, 1994; Thompson, 2003). The demographic transition occurred over centuries in Europe but more quickly in some developing countries over the last few decades in a context of poverty and overexploited natural resources.

Demographic patterns have been linked with urbanization and with improvements in women's education, rights, and health that tend to reduce child mortality and to improve family planning (Caldwell, 2006; Galor, 2012). Developed countries have lower growth rates than developing countries. While convergence is expected, large differences may still remain for at least one century as some countries, mainly in Africa, may maintain high growth rates if current slow decreases in fertility continue (Clarke & Low, 2001; UN, 2004). Further, different 'demographic transitions' have been suggested, relating to shifts in partnership formation (cohabiting instead of marriage), values associated with childbearing decisions (ethics, politics, sex relations, education), and the postponement of parenthood. Their environmental impacts bear exploration (Lesthaeghe, 2014).

The world's population is aging, with consequences for resource consumption and management. The number of seniors – 60 years and above – is growing fast, while those above 80 are increasing even faster (McNicoll, 2002). Seniors are growing faster in urban than rural areas (McNicoll, 2002). Aging in rural areas has implications for the composition of rural labor forces and thus agricultural production patterns, land tenure, social organization in rural communities, and rural socioeconomic development. Such shifts over several decades in developed countries are now taking place in developing and least developed countries, challenging generational replacement that has been central for governance, environmental protection and sustainable use in rural areas. Shifts also highlight poor environmental quality, plus limited access to employment and services – especially for young people – within the rapidly growing urban areas of the developing world.

2.1.4.2 Migration

The amount of people who migrate to a new country has more than tripled in the last five decades **(Figure 2.1.4)**, with about 240 million people living today within a country where they were not born. The number of international immigrants currently is largest for developed countries **(Figure 2.1.4)**, as well as for Europe and Central Asia (Figure S3). The number is increasing fastest, however, within developing countries **(Figure 2.1.4)**, and also in Europe and Central Asia (Figure S3), where the number of migrants has increased fourfold between 1980 to 2010, in both regions.

International and within-nation migration has multiple drivers (Arango, 2017). Large contrasts in political stability, satisfied basic needs, and larger incomes are among some of these key drivers, particularly within the Middle East, South America and Asia. Migration may also be triggered by environmental conditions, with estimates of several million 'environmental migrants' today and with orders of magnitude increases in that group expected in the future (Laczko & Aghazarm, 2009).

Scarcities of resources (Hunter, 2005; Hunter *et al.*, 2005) and unfavourable conditions (Hunter, 2005) can shift populations (Lee, 1966; Todaro, 1969). Such degradation can interact with extreme events, such as those which caused the severe dust storms that occurred in American and Canadian prairies during the 1930s (Cook *et al.*, 2009), leading to the suggestion that migration could be one adaptive strategy for households facing environmental pressure. Rising temperatures have increased internal migration strategies in Brazil, Uruguay and South Africa (Mastrorillo *et al.*, 2016; Thiede *et al.*, 2016). Periods of low rainfall drove both internal and international migration in rural Mexico, particularly from municipalities with rain-fed agriculture (Leyk *et al.*, 2017). Crop failures driven by low rainfall also have fueled migration in Bangladesh (Gray & Mueller, 2012b).

Complex social-ecological interactions also underpin migration across different contexts (Black *et al.*, 2011). Villages and families with more resources (e.g., higher agricultural production) are more likely to engage in costly long-distance migration, as observed in rural Ecuador (Gray, 2009a, 2010), and northeastern South Africa (Hunter *et al.*, 2014). The role of gender is context-dependent (Gray & Mueller, 2012b), with: women's marriage-related migration falling by half during a recent drought in Ethiopia (Gray & Mueller, 2012a); while rural-urban migration increased due to deforestation in Ghana's central region particularly for young men more likely to find urban employment (Carr, 2005). Household characteristics are also important. In the Brazilian Amazon and in Southern Mexico, circular or iterative rural-urban migration is more likely for young adults, whose remittances often help to expand agricultural production (VanWey *et al.*, 2007). Community characteristics also matter, in particular social networks. In the context of Mexico-US migration, for instance, the impacts of environmental and resource risks, such as droughts, on migration are different for communities with expanded social networks due to migration histories (Hunter *et al.*, 2013).

While migration can be a strategy to reduce risks, much environmental migration is involuntary (Hunter *et al.*, 2015). Acute events, such as disasters (Fussell *et al.*, 2014; Lu *et al.*, 2016) and chronic events, such as regular droughts (Bates, 2002; Hugo, 1996; Renaud *et al.*, 2007), lead to involuntary migration. For instance, the disappearance of Lake Chad over the last few decades has been a crisis unfolding over the long term that has both internally displaced people (IPCC, 2007) and generated migrations to other countries (Fah, 2007). In Egypt, water pollution and desertification, with other resource scarcity, has driven migration (UN, 2016b).

The degree to which migration aids household adaptation depends upon specific vulnerabilities, such as the sensitivity of one's livelihood to climate (Warner & Afifi, 2014). Poorest households may be trapped by environmental change, lacking capital and increasingly unable to support even the sending of a migrant to provide remittances (Black *et al.*, 2011). For Bangladesh in 1994–2010, for instance, the poorest households were unable to use migration in response to flooding (Gray & Mueller, 2012b). The poorer also suffer higher exposures to environmental hazards (including climate-related), with fewer alternatives for settling in safer places. Thus, they endure more severe and long-lasting consequences (Blaikie *et al.*, 1994; Gray, 2009b; Gray & Mueller, 2012a; Gutmann & Field, 2010; IPCC, 2007).

Migration can have positive or negative environmental implications for receiving or for sending areas (Adamo & Curran, 2012; Curran, 2002; Fussell *et al.*, 2014; Unruh *et al.*, 2004). In areas sending migrants, depopulation may improve environmental outcomes such as regrowth of forests on abandoned land (Aide & Grau, 2004). Remittances back to sending areas may have positive environmental effects, if they reduce resource dependence by substituting bought goods for local production. However, this often can increase food vulnerability for those who remained. Alternatively, funds could have deleterious environmental effects, if used to expand investments in environmentally damaging practices, such as transformation of agricultural lands into urban and peri-urban parcels for real estate development (de Sherbinin *et al.*, 2008; Meyerson *et al.*, 2007). Migration may also hinder local generational replacement, weakening local environmental governance and resource management initiatives, particularly within the contexts in which global climate change poses strong local pressures upon natural resources (e.g., greater exposure of forests to pests and wildfires) that require local protection capacities (Merino, 2012).

In areas receiving migrants, mixed effects on nature are observed. For instance, migration to destinations with high-value amenities can raise resource and environmental degradation. In frontier mining, agriculture and ranching settlements, populations rise in ecologically sensitive areas (Joppa *et al.*, 2009; Wittemyer *et al.*, 2008), e.g., relocation of farm workers to cassava fields in Thailand (Curran & Cooke, 2008) or settlements of displaced individuals in northern Darfur, Sudan that are associated with lower vegetation due to the expansion of small farming (Hagenlocher *et al.*, 2012). Migration may also shift behaviour in receiving areas if individuals adopt attitudes from migrants. Recent immigrants to the U.S. exhibited greater concern for environmental issues than longer-term immigrants or native-born citizens (Hunter, 2000). Yet it has also been found that immigrants' perspectives about the environment can be at odds with resource management practices in receiving areas, as migrants are not very familiar with local realities and practices (Merino, 2012; Robson & Berkes, 2011).

2.1.4.3 Urbanization

Urbanization has been a significant trend in human settlement and development (**Figure 2.1.4**, Figure S1, Figure S3), driven by many factors and with significant environmental impacts. Globally, urban population rose from ~200 million in 1900 to ~4 billion in 2014 (UN, 2014), at which point over half of the world's population was urban. That share is expected to reach two thirds by 2050, as another 2.5 billion are expected to join urban areas, most in developing countries (CBD, 2012; Elmqvist *et al.*, 2004; UN, 2014). While the percentage of urban population is the highest in developed countries (~75%), it is growing the fastest in least developed and developing countries that rose 2.3 and 1.4 times respectively, respectively, between 1970 and 2017 **(Figure 2.1.4)**. Europe and Central Asia, and America have highest shares of urban population (~ 65% in each) but shares are growing the fastest within Africa (~40% between 1980 and 2010) and within Asia and the Pacific (~25%) (Figure S3).

Megacities with populations over 10 million people continue to arise and are projected to reach 41 by 2030. Small to medium-sized cities are growing the fastest and will be the home for the vast majority of future urban populations (UN, 2014). On the other hand, there are 300–400 shrinking cities in the world, about two-thirds in developed countries, in particular the United States, the United Kingdom and Germany (Kabisch & Haase, 2011; UN, 2014). Comparing IPBES regions, Africa, and Asia and the Pacific are urbanizing fastest, with future expansions in Asia and the Pacific expected to occur mostly in China and India (CBD, 2012; Seto *et al.*, 2011; Sui & Zeng, 2001). By 2050, up to 3 billion people will be living in slum areas within cities, mostly in developing countries (Nagendra, 2018).

Currently, urban areas cover under 3% of lands (Grimm *et al.*, 2008; McGranahan *et al.*, 2005; Potere & Schneider, 2007). Their extent is, however, expected to triple by 2030 (Seto *et al.*, 2012), rising faster than urban population. Much of the growth in urban extents has been observed in coastal regions, with 11% of all urban land in low-elevation coastal zones (i.e., less than 10m above sea level), where people and property are particularly vulnerable to floods and sea-level rise (Güneralp *et al.*, 2015; McGranahan *et al.*, 2007). In China, over 44% of urban land use is within floodplains, contributing to increasingly severe flood hazards (Du *et al.*, 2018). Rapid urban expansion is driven by positive feedbacks between urbanization and economic growth (Bai *et al.*, 2012), which generate further socioeconomic disparities between the coastal and inland regions (Bai *et al.*, 2012).

Urbanization is influenced by both ‘push’ and ‘pull’ factors (Hare, 1999), with job opportunities and services ‘pulling’ migrants while rural poverty, labor surplus, changing values (induced at times by the media and education), and civil conflicts acting ‘pushing’ people out of rural areas. ‘Push’ factors are often stronger, leading to many rural-urban migrants with poor employment and public services, including environmental. Poor neighborhoods in megacities of developing countries typically have poor environmental quality, with precarious access to safe drinking water and sanitation (Nagendra et al 2018). Yet the drivers of urbanization are quite variable (Bloom *et al.*, 2008; Fay & Opal, 2000), with important roles of national policies (Bai *et al.*, 2014). For instance, developed countries typically have higher levels of urbanization, with a strong correlation to productivity and income (Cohen & Simet, 2018). This forms a basis for some countries to promote urbanization as part of a strategy for economic growth, but there are large regional disparities, as well as quite mixed results (Bai *et al.*, 2012; Bloom *et al.*, 2008).

2.1.4.4 Human Capital

Human capital – including education, knowledge, health, capabilities and skills – is a significant component of development, one judged by many to be the largest share of the total wealth of all nations (World Bank, 2018o). That share varies by income level: within the low income countries, ‘produced and natural capital’ are the largest share; while in the high income countries, human capital dominates (World Bank, 2018o). Within that human capital, the levels and types of education influence economic development, including the scale of output, sectoral mix, and techniques used. Yet the relation between education, economic performance, environmental attitudes and sustainability is multifactorial – with factors such as economic and development policies, consumption patterns, and integration within the global economy playing major roles.

Human capital can be strongly affected, for instance, by the roles of women within a labor force. This societal factor can have a strong influence not only on the use of natural capital but also on other forms of human capital (World Bank, 2018o), beyond yielding more total human capital. Between 1995 and 2014, the estimated female share of human capital, globally, rose to ~40% – albeit with regional variations (from 18 to 44%; Credit Suisse, 2018).

2.1.4.4.1 Less Agricultural Extension

Meeting the world’s increasing demand for food while still reducing agriculture’s environmental impacts is one of the defining challenges of our times. Agricultural extension services constitute an important approach, as they may foster more productive uses of our limited natural resources, as in precision agriculture (Bongiovanni & Lowenberg-DeBoer, 2004). On the other hand, they can catalyse degrading shifts in production systems that lead to many losses of diverse traditional farming systems (IPBES, 2018b), or widespread harmful removal of tree cover (IPBES, 2018a).

During the 1960s and up to mid-1970s, rural support via agricultural extension was quite strong, particularly as associated with the Green Revolution. During the 1970s, extension was included explicitly within approaches to integrated rural development. However, public-sector extension became more limited after the 1980s, with its emphasis upon participatory approaches alongside drastic decreases in governmental expenditure on agricultural credits. In Latin America, between 1991 and 2007 such extension expenditures were reduced to below 10% (Figure S8). In addition, private support for such agricultural extension also started to decline around the 1980s, leading to underfinancing, staffing shortages, and the contraction of extension services (FAO, 2017b).

2.1.4.4.2 Indigenous and Local Knowledge

Indigenous Peoples and Local Communities (IPLCs) constitute a significant fraction of the world’s population and occupy a large fraction of the land area of the planet. Between 1 and 1.5 billion people are considered as members of Indigenous Peoples and Local Communities (see chapter 1), whiles estimates about smallholders range from 2 to 2.5 billion people (Zimmerer *et al.*, 2015). IPLCs manage or have tenure rights within ~38 million km^2, in 87 countries (or politically distinct areas), on all inhabited continents, covering over 25% of the land surface (Garnett *et al.*, 2018; Oxfam *et al.*, 2016). Their territories intersect with key areas for biodiversity conservation, including ~40% of all terrestrial protected areas and ecologically intact landscapes (Bhagwat & Rutte, 2006; Foltz *et al.*, 2003; Sobrevila, 2008). Traditional occupations are a key source of livelihoods and income for many IPLCs, thus recognizing their rights to land, benefit sharing, and the corresponding local institutions are crucial for supporting local to global biodiversity conservation goals (Garnett *et al.*, 2018).

Today, indigenous and local knowledge (ILK) is increasingly seen as relevant for sustainable resource use, not only for IPLCs but also more broadly. This reflects a shift from centralized, technically oriented solutions, which have not substantially improved the livelihood prospects for many small farmers (even if helping others). While there do exist multiple differences between indigenous and modern/contemporary knowledge, they still have some substantial overlaps, and ways to leverage the two sources of knowledge – e.g., for optimizing agricultural systems around agroforestry, multiple tree-cropping systems, and soil management targeted at smallholders – are being increasingly sought and further developed (Barrios & Trejo, 2003; Cash *et al.*, 2003).

Yet, the traditional practices stemming from ILK clearly are also declining at the very same time, and across multiple communities (Forest Peoples Programme, 2016; chapters 2.3 and 3). For instance, changes in both values and knowledge can be driven by contemporary education, in which prestige and progress might be associated to the replacement of traditional knowledge, which plays a key role in either the maintenance or the erosion of local worldviews and knowledge (Godoy *et al.*, 2009; Reyes-García *et al.*, 2007). More generally, schooling can loosen people's direct personal interactions with nature and lower traditional knowledge, while also potentially hindering the traditional transmission of knowledge based on direct learning from practice guided by local adults and elders. This occurs by creating cross-generational language barriers and changing cultural values (Godoy *et al.*, 2009; Pearce *et al.*, 2011; Reyes-García *et al.*, 2014, 2007). For instance, formal education can remove children from the everyday lives of families during the periods crucial for learning traditional knowledge (Ohmagari & Berkes, 1997; Ruiz-Mallén *et al.*, 2013), effective transmission of which relies upon observation, participation, and imitation in families and wider local communities. As formal education focuses on abstract and general knowledge, often alien to everyday life and local contexts, it may serve to overwrite elements of traditional knowledge. Thus, different ways of learning (i.e., traditional/local vs. formal) may result in multiple cultural identities (Pearce *et al.*, 2011). Yet, nonetheless, there are cases in which traditional knowledge and formal education have been successfully integrated, e.g., using local language and culture in implementing education and by also motivating traditional knowledge transmission (Barnnhardt & Kawagley, 2005; McCarter & Gavin, 2011; Michie, 2002; Ruiz-Mallén *et al.*, 2013).

2.1.4.4.3 Environmental Education

The patterns and relationships within human behaviours which are related to actions that affect nature started to be more closely assessed in the 1970s and 1980s (Hungerford & Volk, 1990). Results from systematic meta-analyses confirm that while environmental awareness is important, knowledge alone is not enough to motivate pro-environmental action (Bamberg & Möser, 2007; Klöckner, 2013). Also, pro-conservation and environmental attitudes tend to be insufficient for inspiring significant behaviours (Ajzen & Fishbein, 1980; Monroe, 2003; Schwartz, 1977; Stern, 2000). Instead, meaningful childhood experiences regarding nature, in particular in the context of family members who model care for nature, have been linked to adult conservation behaviours (Children and Nature Network, 2018; Clayton *et al.*, 2012; Tanner, 1980).

While a childhood's time in nature is clearly instrumental in developing a lifelong commitment to care for the Earth, a positive and meaningful connection to nature can also be facilitated and enhanced throughout our lives, though, and may start at any time. Nature-based activities have been shown to have instrumental influences on adult behaviour (Chawla, 1998; Wells & Lekies, 2006). Opportunities to cultivate that sense of connection can emerge within rural as well as in urban environments – not only promoting environment-supporting behaviours but also leading to increased health and well-being (Richardson *et al.*, 2016). Several studies have demonstrated a positive relationship between the level of involvement in nature-based activities as diverse as fishing (Oh & Ditton, 2006, 2008), SCUBA diving (Thapa *et al.*, 2006) and bird watching (Cheung *et al.*, 2017; Hvenegaard, 2002; McFarlane & Boxall, 1996), and individuals' concerns for the resources upon which their activities depend. People also grow attached to the specific places where they interact with nature, where they are more likely to engage in conservation actions (Halpenny, 2010; Ramkissoon *et al.*, 2013; Stedman, 2002; Tonge *et al.*, 2014; Vaske & Kobrin, 2001). For those already positive toward the environment, regular time in nature may play an affirming role by keeping nature "top of mind" and increasing the likelihood of taking action to benefit the environment (Manfredo *et al.*, 1992; Tarrant & Green, 1999; Thapa, 2010), all highlighting the importance of regular or even frequent experiences outdoors in nature (Kellert *et al.*, 2017).

2.1.5 INDIRECT DRIVERS: TECHNOLOGICAL

2.1.5.1 Traditional Technologies (Indigenous and Local Knowledge)

Both archaeological and contemporary evidence suggest that humans have used and continue to use a wide variety of deliberate means to manage species within habitats rich in biotic resources (Hoffmann *et al.*, 2016). Indigenous Peoples continue to interact with the planet's ecosystems in many and varied ways: forest managers in the tropical lowlands or in the mountains; pastoralists in savannas and other grasslands; and nomadic or semi-nomadic hunters and gatherers in forests, prairies and deserts (Toledo, 2013). Large groups of Indigenous Peoples are also just small-scale producers, not always easily distinguishable from the non-Indigenous Peoples producing nearby. Within the Andean and Mesoamerican countries of Latin America, the Indigenous Peoples farm much like surrounding small-scale farmers (Bellon *et al.*, 2018), with technology and knowledge flowing between the groups. Similarly, in India, distinctions between scheduled tribes and non-tribal peoples cannot be made solely upon the basis of productive activities. In these and other many cases, non-indigenous and indigenous producers plant crops using similar farming methods (Toledo, 2013), while also broadly contributing to dissemination of technologies and knowledge, such as in cases of agroforestry and other tree-cropping systems that are increasingly important within many regions (Agrawal, 2014). Together, IPLCs and a wide range of smallholder producers contribute a significant share of our global food production.

ILK and related practices are increasingly seen as relevant for sustainable use. This is part of a shift from centralized, technically-oriented resource management solutions that, in many cases, adapt poorly or are even harmful to local quality of life and environment. Beyond ecological knowledge and production technologies, there is increasing appreciation for the importance of local institutions that underlie the local access to, use of, and management of natural resources.

Indigenous Peoples and Local Communities' practices usually are based on a broad knowledge of the complex ecological systems in their own localities (Gadgil *et al.*, 1993). A wide range of outcomes emerge from these relationships, with cases illustrating sustainable resource and others with heavy ecosystem impacts via inappropriate management by local populations. For example, water use within Indian communities has proven to be highly efficient, for storage and distribution. Communities located close to the mountains with abundant precipitation have extensive knowledge about canals, dams, pools in hard rocks, and systems known as *kul*, *naula*, *Khatri* (Bansil, 2004). Indigenous Australians have demonstrated detailed technical knowledge of fire and have used it effectively to improve habitat for game and assist with the hunt itself (Lewis, 1989). Indigenous fire management has been documented across the world for agricultural and pastoral use, hunting, gathering, fishing, vegetation growth and abundance, clearing vegetation, habitat protection, domestic use, medicine/healing and spiritual use (Mistry *et al.*, 2016; Sletto & Rodriguez, 2013). In Brazil, the practice of Mayú, a mutual cooperation in the elaboration of large-scale tasks within traditional farming, e.g., cutting of trees and burning the felled biomass, is one social institution which has facilitated the formation and establishment of social bonding as well as important intergenerational knowledge transfer (Mistry *et al.*, 2016).

In tropical countries, IPLC agroforestry systems are based on ancestral practices with common characteristics. These systems are highly diversified, productive and complex. Producers manipulate species but also vegetation and ecological processes (Toledo & Barrera-Bassols, 2008). As within many regions of the world, in these countries the rotation of harvesting contributes to landscape heterogeneity – and while such rotation in agriculture is well known, less well known is rotation for grazing and hunting and fishing. In semiarid regions such as the fringe of Sahel, for instance, seasonal patterns of rainfall drive migration by larger herbivores and by traditional herding peoples. This can allow for the recovery of grazed lands – which can be disrupted by settlement. Throughout arid and semiarid Africa, traditional herders followed migratory cycles, rotating grazing land seasonally and, in cases, rotating adjacent grazing areas within a season (Gadgil *et al.*, 1993).

Yet, indigenous and local knowledge and practices are being lost, even as they come to the fore. One indication is reduced linguistic diversity. The Ethnologue (Lewis, 2009) identified 6,909 languages – of which half are at risk of extinction**.** Linguistic diversity can be correlated with biological diversity in regions including Taiwan and the Philippines, the Amazon Basin and Papua New Guinea and Eastern Indonesia, Northern and Central Australia, Eastern Siberia, and Mesoamerica. Extinction risks for these elements of linguistic diversity are high in Australia, the Amazon and Eastern Siberia. In many cases, these losses also correlate with the abandonment or transformation of local production systems, with implications for land cover change (involving reforestation and/or deforestation), local food self-sufficiency, and the loss of agrobiodiversity.

2.1.5.2 Technological changes in primary sectors (with direct uses of nature)

2.1.5.2.1 Significant Transitions in Agriculture

Agriculture has expanded significantly, in response to increasing demands – a trend not likely to decline in the near future, given the increases in livestock, human populations, and incomes. Yet such expansions can be either extensive, via increased area, or intensive, via increased yield (output per unit area, often increased through increases in the levels of inputs). At a global scale, intensification can imply greater shares of agriculture in some regions yet reductions elsewhere. Areas can fall while outputs hold steady, with increases in yields, as in high income countries in Latin America and the Caribbean (Figure S9). Illustrating regional variation, agricultural yields and areas rose concurrently in middle income countries, as well as in low- and middle income sub-Saharan Africa. For instance, there was a rise in both land area allocated to cereals and the cereals yield in sub-Saharan Africa, while other areas focused on raising yield without any significant increase in their farming areas. Most of the agricultural producers in this region are smallholders – including those farmers who practice slash-and-burn agriculture, which in some areas has contributed significantly to the losses of forest ecosystems and biodiversity.

Historically, the Green Revolution brought important changes with both opportunities and risks. During the 1960s, 1970s and 1980s, yields of rice, maize and wheat all increased steadily via the application of innovations in seed development, irrigation and fertilizer use. With billions added to the world population, since these practices began, many believe that without gains in outputs, famine and malnutrition would have been much greater. A nutrition expert who led the FAO, Lord Boyd Orr, was awarded a Nobel Peace Prize in 1949. The 'father' of the Green Revolution, Norman Borlaug, was also awarded a Nobel Peace Prize, in 1970, for 'providing bread'. Borlaug promoted the aggressive use of all advances in traditional methods – and then later championed genetic engineering – to develop varieties with greater yields, as well as resistance to diseases.

Yet, the Green Revolution highlights both the immense potential and significant trade-offs from innovations (Abramczyk *et al.*, 2017). Chemicals uses caused environment and health issues (Singh & Singh, 2000; WHO & UNEP, 1989; WRI *et al.*, 1992). Also, intensive fossil-fuel agricultural practices have negatively affected the water table in many regions. Food security fell for some, as production shifted out of the subsistence approaches which had been feeding many peasants in India. Also, monocultures have yielded poorer diets than traditional farming and agrobiodiversity. Looking globally, such practices also can lower food security through greater control of food systems by corporations upon whose inputs small- and middle-scale producers become dependent (Berlanga, 2017) and who may promote diets yielding poorer nutrition. Some practices may be subsidized by national governments, in the favour of large firms (FAO, 2009a). Also, despite food availability, famine has continued to come about, given societal failures (Drèze & Sen, 1991).

For nature, a gain from yields can be 'sparing' of land, i.e., less need for land for a given output (Stevenson *et al.*, 2013). Yet, evidence of land sparing is mixed across scales (local, national and global), intensification types (technology-driven versus market driven) and contexts (governance). Technology-driven increases in the outputs per unit area can reduce the pressure on land (Byerlee & Deininger, 2013) when intensification is far from frontier areas, so demands pull labor away from frontier areas. It can increase pressure by raising frontier productivity – increasing returns to lands (ibid). The market dynamics matter (DeFries *et al.*, 2013; Meyfroidt *et al.*, 2013; Rudel *et al.*, 2009b). For the IPBES regions, Africa responded to such increases in demands by increasing areas, while Asia and the Pacific responded mainly by increasing yields, using investments in both infrastructure and governance (IPBES, 2018b).

Potential adjustments to improve trajectories include applying IPLCs' agroecological innovations. Additional potential adjustments include various uses of biotechnology that, in traditional forms, have contributed for millennia. Providing foods and medicines via farmer selection and breeding of crops and animals has deep roots in local and traditional knowledge. Ongoing uses include a large number of plant varieties (for agrobiodiversity) and livestock breeds adapted to extremely varied soil, climate, disease, predation, and management contexts with specific qualities. These varieties and breeds constitute an asset to preserve for all of humanity, while modern agriculture has tended to homogenize the genetic diversity of crops and herds (see also chapter 2.2).

Further potential adjustments are genetically engineered seeds (genetically modified organisms -GMO) commercialized in 1996 and planted on ~185 million ha, across 26 countries, by 2016 (ISAAA, 2016) to increase insect resistance (IR) and herbicide tolerance (HT) in maize, soybean, cotton and rapeseed, thus lowering damages and crop losses (Lichtenberg & Zilberman, 1986). Hundreds of studies of farm-level impacts of HT and IR including field trials in many countries reveal substantial but not universal yield gain (Carpenter, 2010; Finger *et al.*, 2011; Qaim, 2009). Yet by increasing cotton yields 34%, corn yields 12% and soybean yields 3% such seeds are estimated to have spared 13 million ha of land from agriculture in 2010 (Barrows *et al.*, 2014b). Yield gains should be greatest in developing countries (Qaim & Zilberman, 2003), where pest pressures are higher, but smaller where pest damage is effectively controlled by conventional means (Carpenter, 2010; National Research Council, 2016; Qaim, 2009).

Evidence about lower pesticide and herbicide use due to such seeds is mixed. National Research Council (2000b) reported resistance in only three pest species in the first 14 years of commercial IR cropping, yet the cases have increased over time (Bennett *et al.*, 2004). The NRC (National Research Council, 2016) determined that damaging levels of resistance evolved in some insects targeted by IR crops where resistance-management practices were not followed. For instance, at least 10 species of weeds have evolved a resistance to glyphosate within the United States due to a nearly exclusive reliance on it for weed control (Duke & Powles, 2009). The situation may be improved by uses of varied weed control mechanisms (Barrows *et al.*, 2014a). Overall, as for other innovations, trade-offs emerged for genetically engineered seeds – including increasing costs, though control costs can decline sufficiently to improve farms' margins (Carpenter, 2010).

Trade-offs for GMO seeds might also include environmental concerns, such as impacts on crop genetic diversity, people's health and farmers' livelihoods. Gene flows across GMO and non-GMO seed can result from cross-pollination between GMO and non-GMO plants from different fields, as confirmed for the case of some landraces of maize in Mexico by a board of scientists (Commission for Environmental Cooperation, 2004), thus suggesting more attention is needed (National Research Council, 2010). Genes can also be transferred to wild plant species belonging to the same genus, which may have unpredictable effects. In terms of health, use of the herbicide glyphosate has been linked to an increase in cancer rates and teratogenesis in Argentina (Vazquez *et al.*, 2017) and some data suggest accumulations within the animal and human food chains (Krüger *et al.*, 2014) – yet the US NRC did not find evidence that consumption of GMO foods is riskier than non-GMO counterparts (FAO, 2000; National Research Council, 2000a, 2000b; WHO, 2005). Economic benefits and costs have been documented in varied contexts (Brookes & Barfoot, 2012; Kathage & Qaim, 2012; Qaim & de Janvry, 2003; Qaim & De Janvry, 2005; Zambrano *et al.*, 2009) yet there can exist concerns even about the economic and political pressure upon such science itself.

2.1.5.2.2 Limited Transitions in Biomass Energy

Innovation has also occurred in how energy is produced and used. More than in any other region, though, households in sub-Saharan Africa still depend upon biomass for domestic energy supply – with effects on health and nature (Arnold *et al.*, 2006; Bailis *et al.*, 2015, 2005; Foley, 2001; Ramanathan & Carmichael, 2008; Vlosky & Smithhart, 2011), particularly within East Africa. Approximately 95% of the people in Burundi, Ethiopia, Rwanda, Tanzania and Uganda use solid fuels to cook and to heat (GACC, 2017). Persistence within such behaviours is due in part to societal values of fuelwood, the slow development of markets for modern fuels (e.g., liquid petroleum gas) and clean cookstoves, with little information on personal or social benefits of switching fuels and stoves (Masera *et al.*, 2000; Schlag & Zuzarte, 2008). High capital costs and poor infrastructure have both also further inhibited the household adoption of modern fuels and technologies (e.g., electricity). In western Uganda, fuelwood consumption has contributed to deforestation (Dovie *et al.*, 2004; Ndangalasi *et al.*, 2007; Nkambwe & Sekhwela, 2006)though small-scale agriculture and timber remain the primary drivers (Geist & Lambin, 2002; Jagger *et al.*, 2012; Mwavu & Witkowski, 2008). Outside parks, half of tropical forest on private land is degraded (Nsita, 2005) in part to gain *de facto* property rights (Jagger, 2010).

Land-use change has greatly lowered the standing biomass over quite a short period of time (e.g., 26% in 2003-11). This can induce the planting of trees, as a response to scarcity of biomass. Yet it is only at small scale. Greater responses by rural households are in quantity and source of fuels – with significant shifts away from fuelwood from the forests to fuelwood from non-forest areas, which are larger where significant conversions have lowered biomass (Jagger & Kittner, 2017). More use of crop residues is consistent with this sort of shift. Shifting fuel types and sources has at least two direct impacts, at the level of a household: an increase in the use of low quality fuels, which raising exposures to household air pollution (Forouzanfar *et al.*, 2015); and an increase in the time required to collect fuel, with women primarily bearing the cost (Jagger & Kittner, 2017).

2.1.5.3 Technological changes, and trade-offs, within urbanization and industry

Transport investment and other innovations facilitated urbanization, generating both productivity – as economies diversified into manufacturing and services – and many other consequences. At the landscape level, transport investments also improved market access for peripheral areas. Still, most gains may go to urban areas and the linkages can further raise concentrations (Scott, 2009).

Within cities, transport costs again are critical. Given relatively fixed land areas, scale economies with high density eventually can be offset by congestion, i.e., traffic with time costs, so another urban investment has been in subways (Scott, 2009, chapter 4). Densities also raise the challenges of disease (Scott, 2009, pp. 140–141). Innovations such as vaccines address many threats, including in low income settings today, as do investments in sanitation that still affect choices of locations.

For direct uses of nature, scarcities have motivated innovations, including reductions in material or pollution intensities per unit production. Changes are due to both purely private motivations or regulations (see governance below) and, as consumptions rises, are needed to meet basic needs without raising consequent degradation. As consumers and as citizens, people may be willing to incur costs for cleaner production. For instance, households might on their own invest in stoves (Chaudhuri & Pfaff, 2003; Pfaff *et al.*, 2004a, 2004b; and many studies cited in World Bank, 2007) to produce cooking, heating and lighting services with far less pollution. This applies in rural areas but also has significant spillovers to ambient air quality within cities.

Scarcities of water quality and quantity clearly have motivated innovations, e.g., to purify water (Jalan & Somanathan, 2004) or to find safer sources (Madajewicz *et al.*, 2007). Understanding risk is critical for investments in both piped water (Jalan & Ravallion, 2003) and bottled (Fetter *et al.*, 2017). For water quantity, as for irrigation, at the local and community levels water shortages lead to social innovations such as local upstream-downstream groups to allocate water, as in Sri Lanka (Uphoff, 1996). Analogously, Ostrom (1990) documents a Spanish community's innovations to make water-use reductions physically and socially feasible, despite outputs goals.

Enormous shifts in energy efficiency are occurring, including in renewable energy. High prices for fossil fuels motivate such investments – just as recent lower prices for fossil fuels reduced the intensities of both conservation and exploration. Higher costs such as for extensions of electricity grids on rural frontiers also motivate investments in substitutes, such as solar, that degrade less. The diffusion or spreading of such innovations during industrial development can help nature (Popp *et al.*, 2010) and motivate further investments into research and development (Chuang, 1998; Golombek & Hoel, 2004). Broader use of such innovations could avoid the most environmentally destructive elements of economic development (Carson, 2009; Munasinghe, 1999), allowing 'leapfrogging' to modern technologies, e.g., grid or solar electricity, to furnish urban centers (Liu *et al.*, 2016a). Such diffusion may require regulation (Popp *et al.*, 2010) or subsidies to flourish (Fu *et al.*, 2011; Goldemberg, 1998; Murphy, 2001) yet in cases diffusion could even facilitate economic development (Munasinghe, 1999; Popp *et al.*, 2010) – including within fast-growing economies (Jayanthakumaran *et al.*, 2012).

Yet, as for other innovations, there are trade-offs including for nature – e.g., fossil fuel emissions from cars to windmills that hit birds. Replacing fuelwood with hydropower clearly aids forests and indoor air quality (Liu *et al.*, 2016a) but shifts water flows and flooding, with negative effects on biodiversity and more (Bunn & Arthington, 2002). While antibiotics have saved lives for over a century, and long been used in animal production, aquaculture, and high-value fruits and vegetables (McManus *et al.*, 2002) as well as feeds (Holmstrom *et al.*, 2003; Kumar *et al.*, 2005), they enter the soils plus surface and ground water and drain to coastal bodies of water where they do not readily degrade (Holmstrom *et al.*, 2003). Their widespread overuse also has led to a proliferation of antibiotic-resistant bacteria (Holmstrom *et al.*, 2003; Kumar *et al.*, 2005; McManus *et al.*, 2002) to the point of being recognized by the World Health Organization as a major, global public-health problem.

2.1.6 INDIRECT DRIVERS: ECONOMIC

2.1.6.1 Structural Transition

2.1.6.1.1 Economic Composition (shifts across sectors)

Since 1950, economies have shifted out of agriculture and towards both industry and services, in varied mixes. It is clear **(Figure 2.1.5)** that agriculture's share of value added is higher for low- than for high income countries, while the opposite ranking of shares holds in manufacturing and services.

For low income countries, employment shares across sectors were stable between 1990 to 2016 at ~65% in agriculture, ~9% in industry and ~26% in services. Across the same time period, however, the share of employment in agriculture fell 10% for all the middle income countries (down from ~46% in the lower-middle income and ~27% in upper-middle income countries), while the employment share in industry was relatively stable, rising about 4% during this period. Thus, employment went into services, which rose to ~37% in lower-middle and ~61% in upper-middle income countries, while also rising about 10%, to 73.1%, within high income countries.

Shares of GDP had similar trends, with agriculture falling for all country groups – albeit earlier for the high income but more smoothly for the middle income countries, stabilizing near 9% for upper-middle- and 16% for lower-middle income countries. From the 1960s, industry shares of GDP rose more steeply in high income countries, peaking at about 50% in 1974 while stabilizing at around 20% in low income and ~30% in middle income countries. Service shares increased steadily as well, reaching ~50% in low income and 63% in middle income countries by 2016. For high income countries, after fluctuating, they rose steadily until stabilizing around 68%.

According to the Vienna University of Economics and Business (WU, 2017), industrialized economies in Europe and North America have lowest material intensities (at 0.5 tons of material consumption per US$1000 of GDP in 2013, down from 0.8 and 1 in 1980, respectively). While this can be driven by technology shifts mentioned above, and by increased trade mentioned below, it **(Figure 2.1.6)** is partially due to the shift towards services.

Yet, scale still matters. Since 1950, world population grew by a factor of 2.7 and global material consumption by a factor of 3.7 (Schaffartzik *et al.*, 2014). Furthermore, resource use is unequal, linked to poverty. Western industrial countries that shared 44% of global GDP and 15% of world population in 2010 have been responsible for almost half of the global material consumption. In recent decades, there has been a shift toward China (Muradian *et al.*, 2012).

That shift in relative scales interacts with unequal intensities **(Figure 2.1.6)** to modify global intensities. Expansion in Asia raised average material extraction intensity for the global economy **(Figure 2.1.6)**, although without 'decoupling' the degradation of nature from economic growth (WU, 2017): while Asia's material intensity remained relatively constant for almost two decades after 1980 (at around 2.5 tons per $1000 US GDP), that measure rose (to 3.1 tons in 2013). African economies still have highest intensities but their improvement since 1980 (from 4.2 to 3.3 tons) has also been significant.

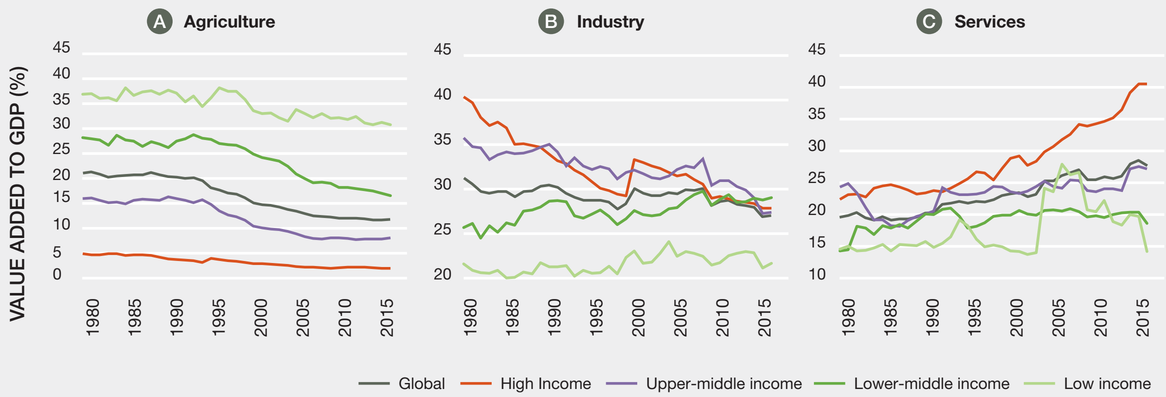


Figure 2 1 5 Changes in economic composition: Value Added in Agriculture A versus Industry B and Services C.

Values per country are averaged for World Bank income categories. Services sum service exports and imports then are divided by GDP, all in current U.S. dollars. Sources: (World Bank, 2018a, 2018b, 2018c, 2018d, 2018e)

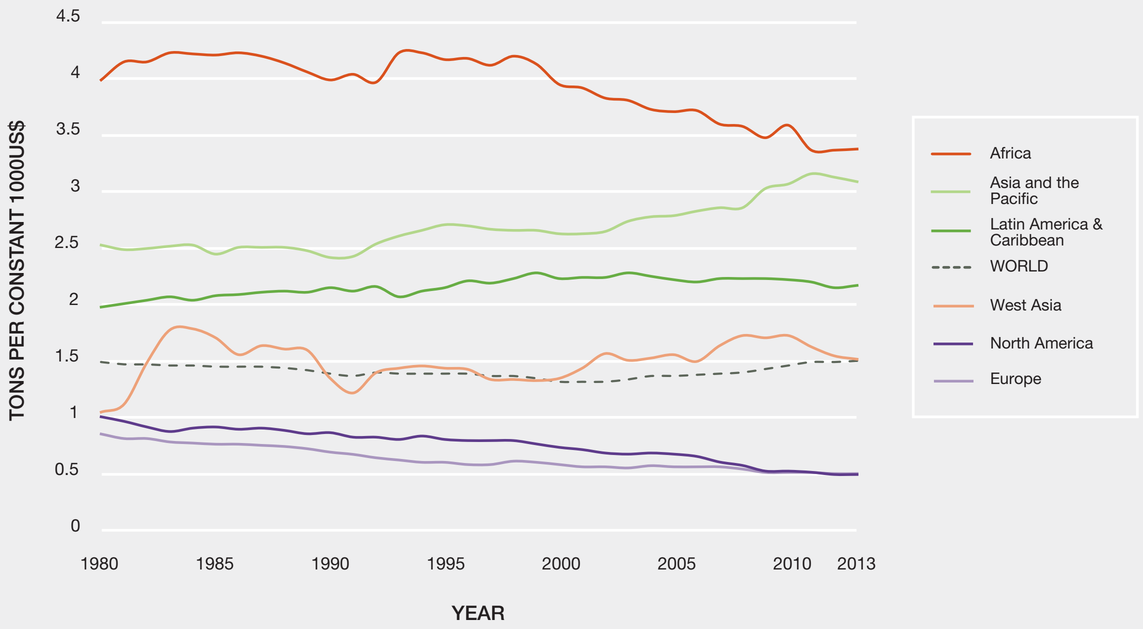


Figure 2 1 6 **Trend of material intensity (domestic material consumption in tons per constant 2005 US$1000 of GDP) by world region (1980~2013).**

Average values for six world regions and the world average for the tons of extracted materials necessary to produce economic output (in 1000 constant US $). Source: UN Environment Programme International Resource Panel Global Material Flows Database (https://www.resourcepanel.org/global-material-flows-database).

2.1.6.1.2 Factors Supporting Sectoral Shifts

Concerns about degradation are one motivation for individuals to put resources into transitions, such as across sectors. Such concerns or values are suggested when people take costly actions to maintain or to improve natural assets (e.g., Atkinson *et al.*, 2012; Freeman *et al.*, 2013; Merino & Martínez, 2014; Smith, 1996), e.g., treat water or use improved cooking technologies (Alberini *et al.*, 2010; Pattanayak & Pfaff, 2009), conserve ecosystems (Ferraro *et al.*, 2012; Kramer, 2007; Majuru *et al.*, 2016) and forests (Merino & Martínez, 2014). Scarcity of nature shifts the value placed on nature, as in the 'diamond-water paradox' (Farber & Griner, 2000; Heal, 2000): water is essential to sustain life yet, when perceived as plentiful, is used in non-conserving ways (Barnett & Morse, 1963; Pratt & Zeckhauser, 1996). Willingness to incur costs to shift behaviours also depends upon the belief that costs will be shared among interested parties and have positive outcomes. For instance, if families perceive that others free-ride on their actions, not engaging in contributions but benefiting, they too might free ride (Graves, 2009; Matta & Alavalapati, 2006; Starrett, 2003). Still, given a chance they may vote for rules that bind behaviours (Álvarez-Farizo *et al.*, 2007; Starrett, 2003; Wilson & Howarth, 2002; Wiser, 2007).

Beliefs about or perceptions of risk across sectors can help to drive such economic transitions (Lubell *et al.*, 2007; Whitehead, 2006). It can be hard to ascertain environmental quality, resulting in misaligned perceptions of safety and incorrectly low demand for actions that support nature (Orgill *et al.*, 2013). Salient information about the lack of environmental quality can spur demands for adjustments (Brown *et al.*, 2015; Hamoudi *et al.*, 2012; Madajewicz *et al.*, 2007). Within the provision of such information, one key issue is the multidimensionality of environmental amenities or, more generally, nature. For example, dimensions of drinking water that can affect behaviour include: price, convenience, reliability, taste, turbidity, and more (Farber & Griner, 2000; Jeuland *et al.*, 2016, 2014; Ma & Swinton, 2011). As a result, offering information on water's reliability alone may achieve little if other features affect decision trends.

When markets perceive scarcities, price rises, providing incentives to invest, as in forests (Foster & Rosenzweig, 2003), while countries may respond with policy (Mather, 2004; Mather & Fairbairn, 2000; Mather *et al.*, 1999a); for example, Bae *et al.* (2012) argue that South Korea's forest transition was due in some measure to reforestation policies. A different dynamic is a buildup of human capital that facilitates a switch to industry (Choumert *et al.*, 2013; Mather *et al.*, 1999a). Hecht *et al.* (2015) highlight the roles of urbanization and remittances in behavioural shifts (e.g., farmers migrate to the cities), while if populations stabilize, implying less growth in demands for crops, and in labor supply for agriculture, that can result in reduced pressure for new deforestation (Angelsen, 2007; Wolfersberger *et al.*, 2015). For instance, Rudel *et al.* (2000) found that for Puerto Rico, non-farm jobs pulled labor out of agriculture; agricultural production could then become more intensive, which could reduce the pressures on forests, while some agricultural lands could revert to forest (Rudel *et al.*, 2005). This lower pressure on forests can also result from a reduction of fuelwood collection (DeFries & Pandey, 2010).

2.1.6.1.3 Implications for Nature of Sectoral Shifts ('composition effects')

Sectoral shifts affect nature. A substantial literature during the 1990s found relationships between pollution concentrations and GDP per capita using data since World War II: as GDP per capita increases, pollution concentrations rise then fall (Gale & Mendez, 1996; Grossman & Krueger, 1991, 1995; Hilton & Levinson, 1998; Selden & Song, 1994; Shafik & Bandyopadhyay, 1992). In general, however, it appears that the specific relationships between pollution and economic growth can be quite different across the many types of pollutants, including in that they can be sensitive to the period of study and the quality of the data (Carson, 2009; Harbaugh *et al.*, 2002; Stern, 2004; Stern *et al.*, 1996). This speculative relationship was labeled the 'Environmental Kuznets Curve' (EKC, as a reference to Simon Kuznets' ideas in the 1950s about patterns of economic inequality for economic growth).

Parsing such patterns, Copeland and Taylor (2013) distinguish a few underlying changes that occur with the growth of an economy. Thus, when considering policies to shift outcomes, one might focus on any of these dimensions. The 'scale effect' refers to effects of the amount of production. The 'composition effect' refers to a change in the mix across types of economic activity – recalling that such changes in the sectoral mix could occur in part as a result of international trade. Last is the 'technique effect' that can apply to any type of economic activity, in which for private reasons and due to public policies innovations, as discussed above, there are lower damages per unit output for any sector (Brunel, 2017; Grether *et al.*, 2009; Shapiro & Walker, 2015). Some studies evaluate whether international trade induces such effects (Cherniwchan *et al.*, 2017; after Antweiler *et al.*, 2001; Cole & Elliott, 2003; Levinson, 2009; and Managi *et al.*, 2009).

These three effects can sum up to reverse trends for nature. One example of nonlinear and trend-reversing behaviour during economic development has been forest cover, i.e., 'forest transitions' (Mather, 1992). Various such sequences have been observed across the globe (Belay *et al.*, 2015; He *et al.*, 2014; Mather, 2007; Mather *et al.*, 1999b; Meyfroidt & Lambin, 2011; Rudel, 1998; Rudel *et al.*, 2002). While these forest cases do differ, their commonality is that in each case the trend in land use has been reversed (Barbier *et al.*, 2017) due to shifts in human choices, given changes in decision conditions. **Box 2.1.1** highlights the importance of understanding these dynamics well.

2.1.6.2 Concentrated Production

Corporations and financial agencies now control amounts of financial capital, which rival the revenues of the vast majority of countries. The top nine largest economies are countries but at least one company on its own could be the next largest, with larger revenues than the economies of India, South Korea or Australia (Anderson & Cavanagh, 2000). Another five corporations are, then, among the 22 largest 'economies' using these measures of size. One oil company, for instance, has a larger 'economy' than Mexico, India or Sweden. This size can affect the bargaining over any number of exchanges, from contracts with laborers to the exchanges of varied goods in which nature is embedded.

Box 2 1 2 **Examples of supply chain concentrations relevant for uses of natural resources.**

Coffee Despite variations, coffee beans have long been viewed as an undistinguished commodity. Around 70% of coffee is grown in farms under 5 ha (Fitter & Kaplinksy, 2001), so market power is at the other end of the supply chain: 10 global importers control over 60% of global trade. In some countries, buyers collude to drive down prices. Similarly, roasters are highly consolidated, e.g., five European companies controlled over 58% of the market in 1998. This affects governance of the chain and revenues by stage. Producers' prices remained flat or fell slightly over time while consumer prices increased and, in 1995, only 40% of the price stayed in the producing country to be split between producers and traders, implying at best zero rents at the start of the supply chain (Fafchamps & Hill, 2008; Fitter & Kaplinksy, 2001). A survey in Uganda in 2003 showed that the volatility of farm-gate prices did not reflect world prices, consistent with local traders exploiting small farmers' relative lack of information. Recently, though, the industry gives more attention to some of the characteristics of production locations. That can shift some market power to producers changing local communities' incentives to invest in nature and shifting the trade-offs from using it.

Horticulture (fruits and vegetables) Similar results hold in horticulture – boosted by transportation and refrigeration

Box 2 1 2

technologies. Many developing countries with geographical advantages in fruit and vegetables supply, including in Africa, try to reach European markets. Yet, European food retailing is extremely concentrated with the top 5 supermarket chains serving approximately 50% of the market in 1996, with producing countries capturing only 40% of the value. Europeans' demands for higher phytosanitary, social, and environmental standards – plus high predictability – helped out the larger exporters as well. In Kenya and Zimbabwe, for instance, few individuals and companies had capital to export (Dolan & Humphrey, 2000) and such opportunities made them more productive and also more successful within their domestic markets (Pavcnik, 2002). For flowers, recent technological innovations supported expansions by the traditional producers. Ecuador possesses advantages with year-round supply and cheap labor – yet without producer cooperation and differentiated products these advantages do not yield market power. If flower producers are not aware of final market conditions but informed by few importers, they get small profit shares. These dynamics affect the linkages from consumption to degradation and its local net benefits.

Textiles and Apparel In the 1980s, Mexican producers of blue jeans, for instance, moved from serving a small domestic demand to serving the US by partnering with 4 major manufacturers (Bair & Gereffi, 2001). By 2000, several top US retailers joined them, expanding the market. However, the fairly homogeneous nature of their output and a reliance on external inputs was conducive to only small rents, spurred an attempt at upgrading into marketing and design via their own brands. Yet, as in African horticulture, only the few most productive and capitalized firms could manage this. That increased market power and concentrated rents for a domestic elite (Bair & Gereffi, 2001) – while pushing down wages, which exacerbated domestic inequities. The textiles trade used to be driven and governed by cotton producers. However, consolidation of retailers shifted the governance of the supply chain downstream. Thus, cotton producers have shifted to trying cottonseed processing, where market power is not so menaced by international competition and shifting demands (Hutson *et al.*, 2005). Generally, shifts in the power between retail, upstream, and intermediate actors are important for understanding growth implications for the newly industrialized economies (Conway & Shah, 2011). Many developing countries are exporting textiles given foreign requirements that could boost internal productivity. Yet, in terms of surpluses earned, this may raise in-country surplus yet not help cotton per se. All of the dynamics are important determinants of the economic and environmental trade-offs faced, an understanding of which in this case can greatly inform policies focused upon water pollution.

Furniture (forests upstream) This chain has five main stages: forestry; sawmills; manufacturers; buyers and retailers. Demand shifts and retailer innovations raised retail competitive pressures and buyer concentration (Kaplinsky *et al.*, 2003). Traditionally labor intensive, this chain has a trend of falling prices, driven by rising competition and global price convergence with global sourcing (Kaplinsky & Readman, 2005). Buying is now done by a few actors who control higher-value-added activities such as marketing, design and after-sales service. Manufacturing is heterogeneous. South African producers are traditionally large, yet Kaplinsky *et al.* (2003) note declining prices due to the better competitive positions of buyers and suggested shifting into a different value chain (Saligna wood), with varied uses that allow entry with higher unit prices. Ivarsson and Alvstam (2010) examined firms' subcontractors in China and South East Asia. Over half sell over 60% of output to one firm, whose bargaining power implies a larger share of surplus, consistent with Gereffi *et al.* (2005) since the captive supplier is subject to the market power of that 'lead firm' (see also taxonomy in Milberg, 2004). Which chains suppliers sell into greatly changes their incentives for conservation of nature.

Large financial players also have emerged*.* Those include private equity investors, such as infrastructure investment funds, or institutional investors, such as pension and mutual funds (particularly mandatory pension contributions), all attracted by opportunities including the large infrastructure developments (Arezki *et al.*, 2016). To some extent, an increased role for private capital goes along with a reduced or altered role of governments within infrastructure investments. In addition, complex instruments and funding flows can make it hard to trace the lines of ownership, or responsibility, affecting governance.

2.1.6.3 Trade

2.1.6.3.1 Goods & Materials Flows

Flows of goods and inputs rise as smaller shares of resource needs are satisfied domestically and separates consumption from production (Lenzen *et al.*, 2012b). Over three decades, the global exports of food have risen 10-fold (UN COMTRADE, 2013). Trade that crosses national borders affects 41% of materials extracted (Robertson & Swinton, 2005; Wiedmann *et al.*, 2015).

Comparing regions, North-East Asia is by far the biggest net importer of raw materials **(Figure 2.1.7)**, with very high net imports of ferrous metals, petroleum and coal per China's enormous demands for these raw materials within industry and infrastructure. The biggest net exporters are Oceania (mainly Australia), Eastern Europe (mainly Russia), South America (mainly Brazil) and Western Asia (mainly Saudi Arabia) – which export based upon immense natural-resources endowments. Australia has large deposits of metal ores and coal, for instance, while for Russia oil and gas reserves have played important economic roles, yielding considerable export revenues.

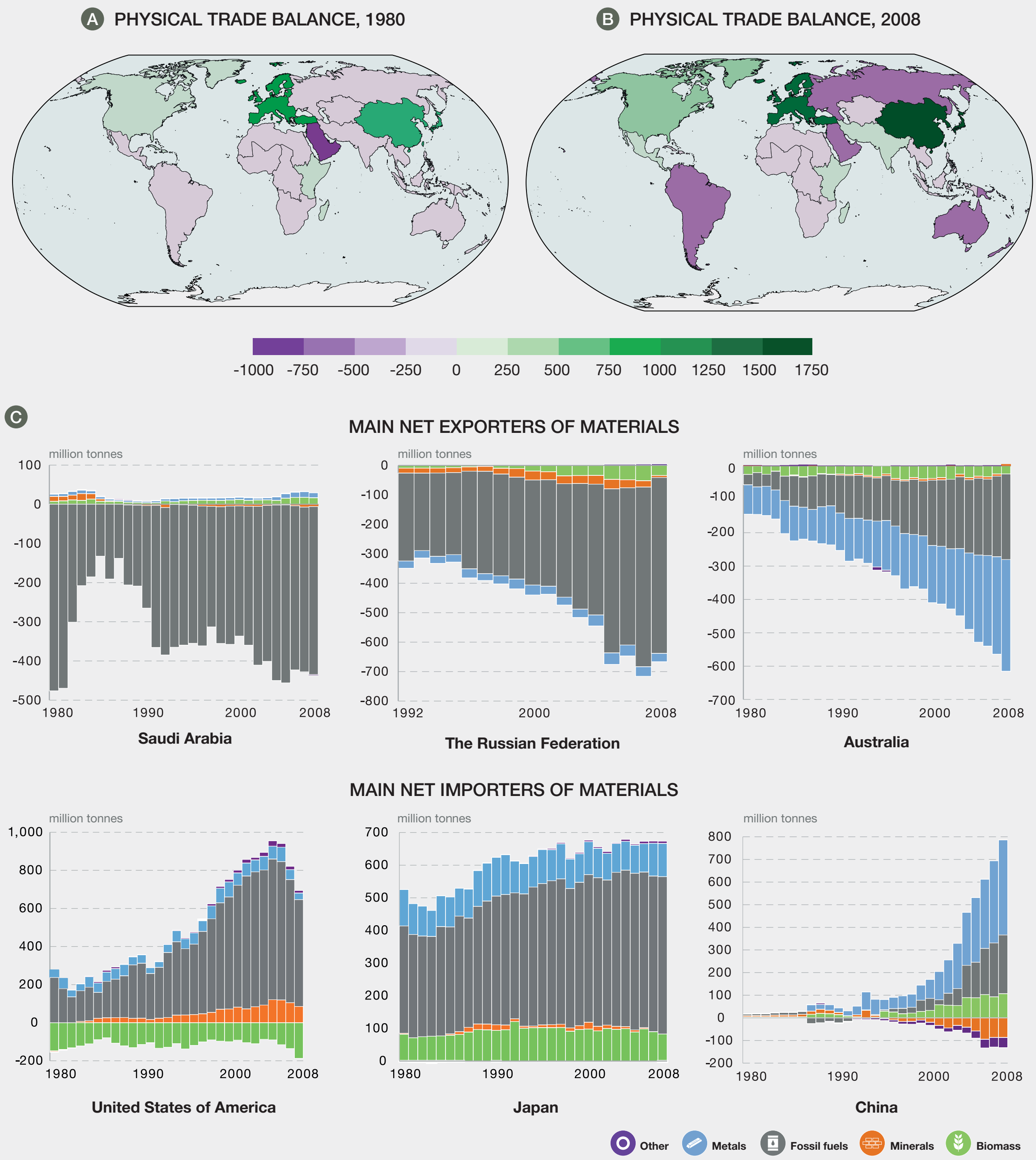


Figure 2 1 7 **The physical dimension of global trade. Physical Trade Balances, by IPBES regions, A in 1980, and B in 2008 (millions of tons).**

The regions in magenta are net exporters of materials, while regions in green are net importers. Underneath are the top three countries in terms of both net imports and net exports, by material categories and physical trade balances. Source: own elaboration with data from WU (2017) (A, B); Dittrich *et al.* (2012) C.

2.1.6.3.2 Telecoupling and Spillovers: trade-offs embedded within the trading of goods

Ecosystems are ever more shaped by distant interactions among countries or 'telecouplings' as the world is becoming more global. Telecouplings refer to socioeconomic and environmental interactions over distances (Sun *et al.*, 2017). Spillovers occur as a result of these telecouplings: effects of (seemingly unrelated) events in one region clearly are experienced in other regions.

The growing trade of goods implies many displaced impacts upon nature – between one quarter and one half of the environmental impacts from consumption are felt in regions other than where the consumption occurs: CO_2 emissions, chemical pollutants, biodiversity loss, and depletion of freshwater resources (IPBES, 2018a). For instance, 30% of threatened species (Lenzen *et al.*, 2012b) and 32% of the consumption of scarce water, i.e., water used within regions with water scarcity (Lenzen *et al.*, 2013), have been linked with international trade. This illustrates spillover effects from consumption of traded goods, in which environmental costs from the production of goods to supply international markets are being incurred far from where the consumption occurs.

Displaced deforestation, pollution, water scarcity, soil loss, and erosion all occur at the expense of ecosystems in other countries, in particular developing countries (Lenzen *et al.*, 2012a, 2013; Moran *et al.*, 2013). Studies considering the impacts on biodiversity. Chaudhary and Kastner (2016) found that 83% of total species loss is due to agriculture for domestic consumption while 17% is due to the production for export. Exports from Indonesia to the USA and China generate high impacts (20 species lost regionally for each). An estimated 485 species currently face high risks of extinction in 174 countries, with about one third of those being a result of current land use patterns **(Figure 2.1.8)**. Perhaps 12% of premature deaths in 2007 from air pollution were caused by pollutants generated by other regions, with 22% arising from the exports of goods and services (Zhang *et al.*, 2017). Exporters get economic returns and technological advancements (Daniels, 1999) but also host negative environmental consequences (Schmitz *et al.*, 2012) – including from monocropping plantations, e.g., for soybean in the Amazon and Chaco, avocados in Central Mexico or cotton, sugar, palm oil and biofuels elsewhere, with health impacts (Lin *et al.*, 2014; Zhao *et al.*, 2015).

It is important to recall that sustainability in one country can rely upon unsustainability in others. Meyfroidt and Lambin (2009) find a 'forest transition' in Vietnam involved displacing extraction elsewhere (Dasgupta *et al.*, 2002; Levinson & Taylor, 2008; Stern, 2004; Suri & Chapman, 1998). In the US, the New England region's forests regrew as railroads linked to the Midwest region that grew in exports due to high agricultural productivity (Pfaff & Walker, 2010). Along those lines, Kull *et al.* (2006), Meyfroidt *et al.* (2010), and Meyfroidt and Lambin (2011) tracked trade to link with forest transitions. Leblois *et al.* (2017) find that countries at the beginning of forest transitions deforest thanks to trade, while those at the end reforest from trade.

Trade redistributes emissions of greenhouse gases **(Figure 2.1.8)**. Production for international markets links with 26% (Peters *et al.*, 2011) to 30% (Kanemoto *et al.*, 2014) of global carbon emissions. However, such effects have been neglected in the relevant international treaties, as carbon accounting was considered solely per country – without including the shifting of emissions from importing to exporting nations (Kanemoto *et al.*, 2014; Peters *et al.*, 2011). These spillovers in fact are larger than reductions in emissions. Thus, relocation of production and degradation affects evaluations of net impacts of governance. Regulations on emissions may appear to be 'effective' in regulated locations, even if degradation simply has shifted to other regions. For instance, since 1990 the UK had measured reductions of up to 16% of domestic CO_2 emissions within its energy and water sectors, yet the CO_2 emissions embodied in imports in those sectors, i.e. those emissions associated to the production of products that are imported, rose 208% in the same time period (Kanemoto *et al.*, 2014).

As to the motivations for such enormous increases over time in the global trade interconnections (and maybe for the lack of interest in tracking them for governance), without a question national scarcities of nature's contributions often have been part of the drive underlying country interests in accessing the nature elsewhere, either directly or embedded in outputs (Figure S11) (Galli *et al.*, 2012; Verones *et al.*, 2017). Exports from the global South, for instance, often have been based on natural assets, including oil and gas (Muradian *et al.*, 2012) that were demanded by countries with growing economies but also growing scarcities of energy. Among the importers of nature, Europe had highest trade flows balances which shifted nature's degradation elsewhere (Dittrich & Bringezu, 2010), yet natural flows are a global phenomenon. In short, as illustrated in **Figure 2.1.8**, exports can have significant costs in local nature degradation.

Turning to potential socioeconomic trade-offs involved, which can vary with implementation as trade can occur on positive or negative terms, the large trade flows sometimes have arisen under contracts with unbalanced sharing of gains (Arduino *et al.*, 2012) and such inequities can get institutionalized in intergovernmental agreements. Merme *et al.* (2014) find different distributions of hydropower benefits in the Mekong Basin under actual contracting than would be expected if all exchanges had occurred under transparent contracting in which all parties were fully informed. Arduino *et al.* (2012) consider how many rentals of valuable lands occurred for low fees, evading Tanzanian laws (and resulting in water pollution). Houdret (2012) connect costly uses of water to the mismanagement of public-private partnerships in Morocco. Transboundary rivers feature conflicts (Biswas, 2011), e.g. a lack of trust between India, Nepal, and Bangladesh over the Mahakali River Treaty despite prior political processes (Khalid, 2010).

In such contexts, some refer to resource exchanges not as 'trade' but as 'grabbing' – in order to explicitly question the adequacy of the levels of compensation involved (Dell'Angelo *et al.*, 2018; Franco *et al.*, 2013). The appropriate label is not always clear. Acquisitions without compensation, such as water diversions or cross-border pollution ("e-waste" in Awasthi *et al.*, 2016), may clearly be 'grabbing'. Yet, adequacy of compensation is "in the eyes of the beholder". Trade can allow all countries to gain from others' strengths, but price is critical for equity – including when the global South imports (potentially displacing production). 'Grabbing' parties may justify transactions by arguing that their investments raise the access to or the productivity of underutilized resources. That possible efficiency rationale for the external inputs does not directly address the distributional consequences for vulnerable local populations.

Nature-economy trade-offs also arise in the conservation of nature in lower-income and least developed countries that effectively exports global public goods, such as carbon storage or species habitat, through forest protection. This may earn global funding transfers, also raising issues of adequate compensation. Overall impacts upon local well-being depend on who gets paid, how much, in which conditions.

Concerning lands, over 1000 deals have been recorded, globally, covering ~50 million hectares. Africa hosts over 400 for ~10 million hectares (Anseeuw *et al.*, 2012; Nolte *et al.*,

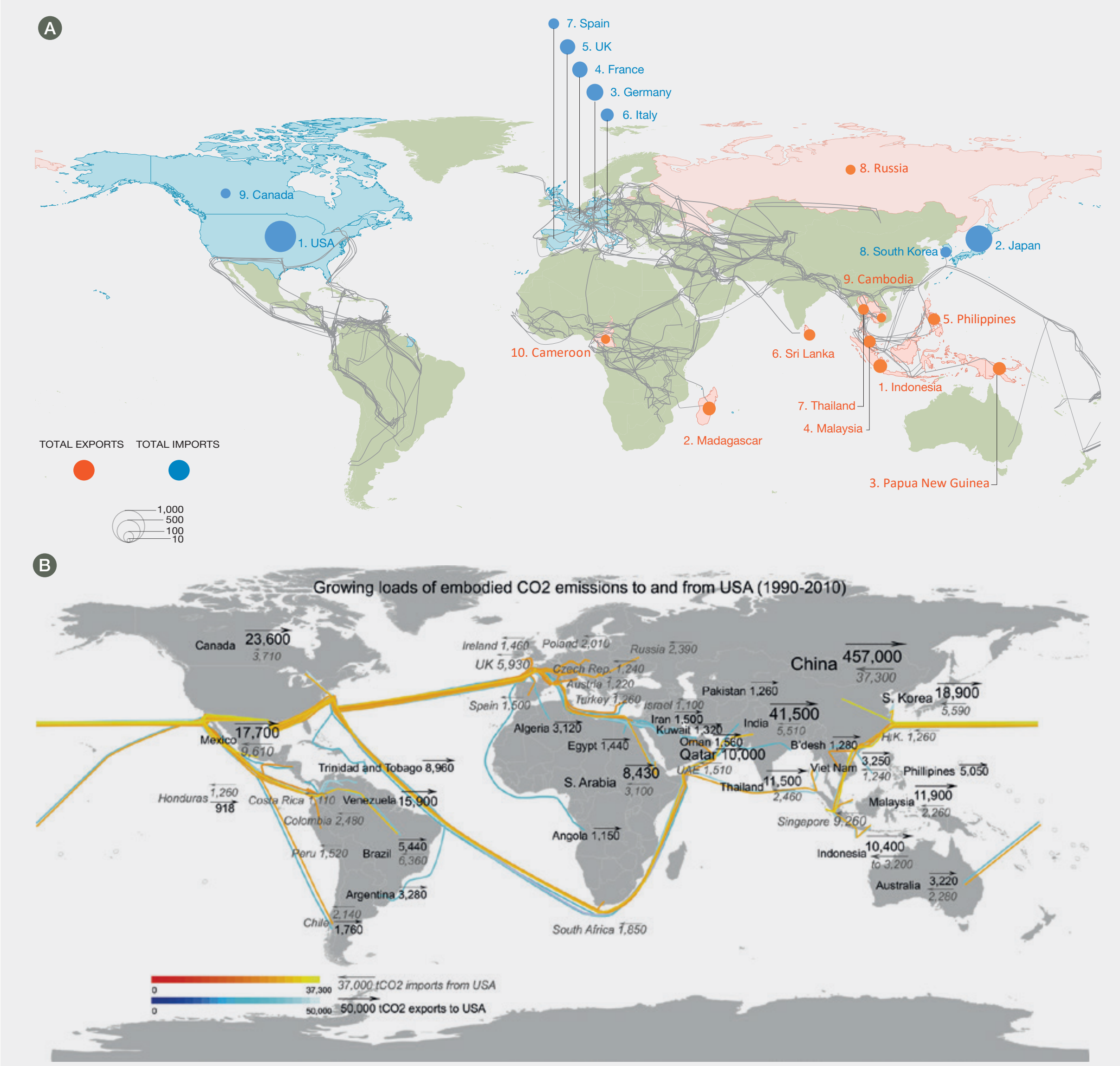


Figure 2 1 8 **Global trade imports and flows measured as biodiversity and CO_2 footprints.**

A Biodiversity footprint showing top ten exporting countries associated with pressures on biodiversity in developing economies and top ten importing countries with respect to pressures on biodiversity (developed and emerging economies); thicker arrows indicate a larger number of threatened species associated with that bilateral trade flow. B Largest growing flows of embodied CO_2 (amount of CO_2 emissions associated to the production of products that are imported to the USA (rightward arrows) and from (leftward arrows), measured as absolute growth 1990-2010 in tons of CO_2). Source: (IPBES, 2018a; Kanemoto *et al.*, 2014; Lenzen *et al.*, 2012a).

2016). Rulli *et al.* (2013) estimate up to 1.75% of cultivable land has been 'grabbed'. Many deals involve conversion of savannah or forest to crops or trees such as oil palm (Borras Jr & Franco, 2012), using water from river basins (Borras Jr *et al.*, 2011). In Africa, investors are largely firms, at times in partnerships with national and local governments. Little evidence exists concerning free, prior, and informed local consent. Instead, weak consultation is reported, yielding protests since customary ownership and custody, with stewardship, coexists with legal state ownership that locally may not be seen as legitimate (Nolte, 2014; Nolte & Väth, 2015). Projected local benefits, e.g., productivity and thus job creation that often is used as justification, have been mixed (Kleemann & Thiele, 2015; Nolte & Väth, 2015). The potential for such conflict must reflect the large shares of global lands held under customary or community-based local regimes (IUCN, 2008), including a significant share held or managed by Indigenous Peoples and Local Communities (see chapter 1) (USAID, 2012).

As to existing plans to address the world's growing agricultural demands, linked also with water, within sub-Saharan Africa, Latin America, Eastern Europe and Central Asia, the lands said to be "available" often also are under formal public ownership and yet used by local groups, including indigenous communities (RRI, 2014). The same issues may arise, then, since regions may suffer implicit "land grabbing" by the consuming countries, via production of agricultural exports which can threaten local food security. The "available" lands also sometimes coincide with areas of high biodiversity. Summing up, if and when lands are converted, justice concerns potentially add to costs in terms of losses of ecosystem services (Sayer *et al.*, 2008).

'Water grabbing' raises all of the same issues as above, again including for agriculture, as noted, and for mining or hydropower generation or often for industry (Merme *et al.*, 2014; Sosa & Zwarteveen, 2012). For the irrigation of cultivable land, demands have been labeled "green" – i.e., extracted by the plants – or "blue" – i.e., pumped (Dell'Angelo *et al.*, 2014; Rulli *et al.*, 2013).

2.1.6.4 Financial Flows

2.1.6.4.1 Remittances

Growing financial remittances after migration, i.e., transfers back to migrants' places of origin, can significantly affect important outcomes for nature within the sending regions. From 1990 to 2015, such remittances rose over 5-fold and were particularly important for poor households in developing countries (e.g., China, India, Philippines, Mexico have the largest absolute inflows of remittances while, as fractions, Tajikistan, Nepal, Moldova and Haiti are high, ranging from one fifth to half of GDP). In 2014, 250 million migrants sent 583 billion US dollars. As the remittances raise disposable income, they can alter consumption patterns in communities. That can, in turn, promote land-cover change due to growth of agricultural activities that need land. In other cases, however, migration yields reductions in subsistence agriculture and, thus, the pressures on lands.

Nine out of the ten most biodiverse countries, globally, are characterized by large- and medium-sized diasporas plus medium to high dependence on remittances. The countries with the largest share of forest lands are not, however, high in migration or dependent upon remittances. Among the top ten countries in the world in terms of highest deforestation rates from 2000 to 2012, only China and the Democratic Republic of Congo have high migration – but even they have low and medium dependence upon remittances. None of those top ten have high remittances per capita.

2.1.6.4.2 Financial Standards

Private investments also are growing and can be very influential. Yet financial returns often do not recognize nature's contributions (World Bank, 2018o). For instance, for sub-Saharan Africa, despite substantial risks of natural depletion, in official assessments total wealth changes are not considered even for large investments. Thus, natural regrowth is not valued, while short-term income from the degradation of nature is counted (World Bank, 2018o).

International institutions can set out environmental and social standards for financial institutions and transactions that borrowers should follow throughout project cycles. Standards can help in doing due diligence to assess risks (EIB, 2014; IFC, 2012; The Equator Principles Association, 2013; World Bank, 2017b). Considering environmental, social and governance (ESG) factors in principles facilitate risk management (Sullivan *et al.*, 2015; van Duuren *et al.*, 2016) that with appropriate counting raises the risk-adjusted, long-term returns from investments (WEF, 2013) and affects assessments of firms' performance (Delmas & Blass, 2010) and financial portfolio (Vörösmarty *et al.*, 2018). By 2016, $23 trillion of assets were managed with 'responsible' strategies that could be of this type – a rise of 25% since 2014 (US SIF Foundation, 2016). Some fund managers aim to track performance with regard to the Sustainable Development Goals, while others track specific social or environmental objectives (Global Impact Investing Network, 2017; GRI *et al.*, 2015; Polasky *et al.*, 2015). Some ideas have been agreed for such guidelines (e.g. The Natural Capital Declaration, GRI Standards for Environmental Reporting; SASB Sustainability Accounting Standards) (GRI *et al.*, 2015; NCFA, 2018; SASB, 2014) but metrics remain a major challenge.

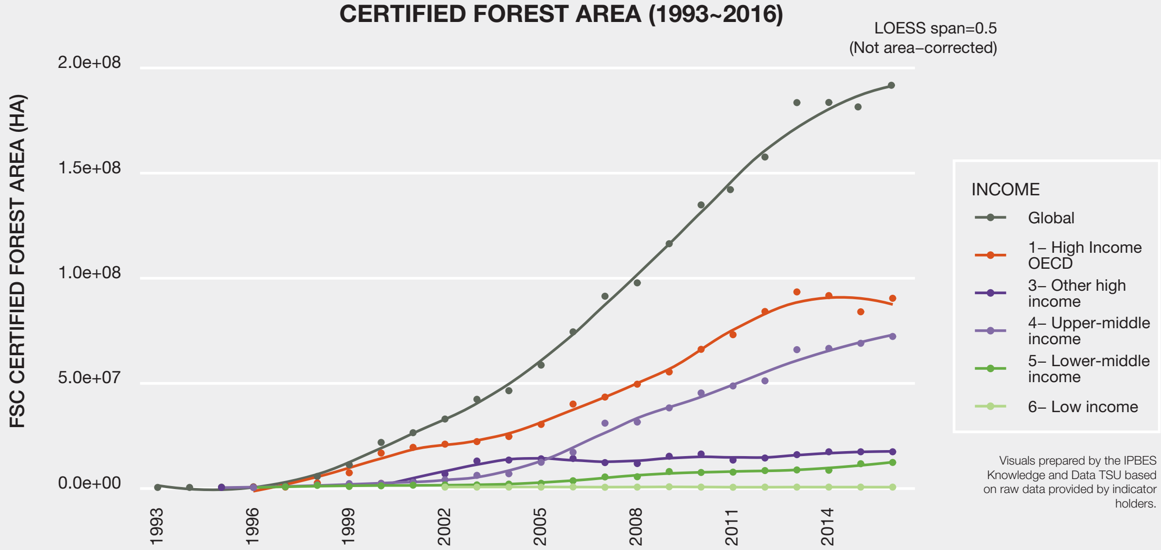
2.1.6.4.3 Tax Havens

The roles of tax havens in the global outcomes for nature are only starting to be documented, given ever larger roles in the global economy. Recent evidence starts to identify possible links between the use of such jurisdictions and the environment (Galaz *et al.*, 2018). Funding via tax havens has been shown to have provided 68% of foreign capital for Amazonian soy and beef production and to have supported 70% of the vessels implicated in illegal, unreported and unregulated fishing.

2.1.7 INDIRECT DRIVERS: GOVERNANCE – MARKET INTERACTIONS

Certification schemes aim to inform supply chain production and consumption. Market-based schemes aim to signal consumers' values to provide incentives for producers to shift processes (Haufler, 2003; Mayer & Gereffi, 2010; Raynolds *et al.*, 2007). Environmental certification exists

A CUMULATIVE SUM OF FOREST STEWARDSHIP COUNCIL (FSC) CERTIFIED FOREST AREA (1993~2016)



B FISHERIES CERTIFIED BY THE MARINE STEWARDSHIP COUNCIL (MSC) (1999~2015)

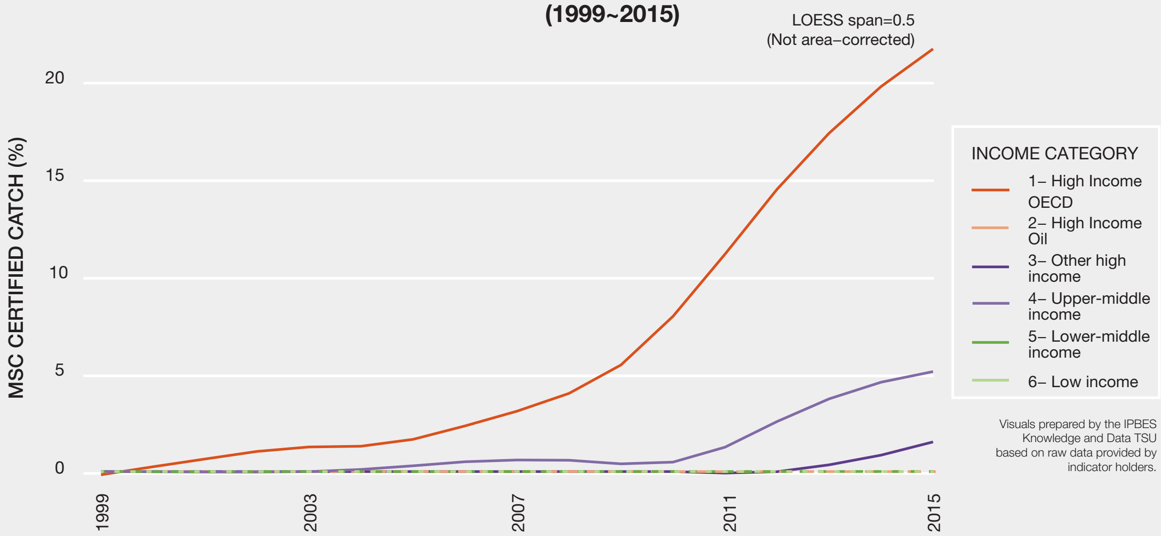


Figure 2 1 9 **Temporal trends in certifications.**

A Cumulative sum of FSC Certified Forest Area (1993~2016); B percentage of fisheries certified by Marine Stewardship Council (1999~2015); this is the sum total of all green weight catch from all certified fisheries, or the weight of landed fish before processing (catch of whales, seals and other aquatic mammals are not included when calculating global catch to compare to MSC fisheries as they are out of scope for MSC certification). Trends show averages from country data, using the World Bank income categories Source: (FSC, 2017).

for a wide range of products – including timber (Klooster, 2005; Molnar *et al.*, 2011) coffee and cocoa (Raynolds *et al.*, 2007; Tscharntke *et al.*, 2015), fish (Constance & Bonanno, 2000), soybean and palm oil (Schouten *et al.*, 2012), nuts and other non-timber forest products (Shanley *et al.*, 2002), horticulture (Hatanaka *et al.*, 2005), floriculture (Hall *et al.*, 2010), biofuels (Selfa *et al.*, 2014) and tourism (Font *et al.*, 2007). Certified area for forests and marine schemes has increased greatly since 2000 **(Figure 2.1.9)**.

Standards dictate the information included within 'labels', which inform actors along the supply chain. They might stimulate a willingness to pay on the part of consumers who value particular practices, as well as firms concerned about their brand reputations as well as political responses (Bartley, 2007; Cashore, 2002; Gereffi *et al.*, 2001; Hatanaka *et al.*, 2005; Potoski & Prakash, 2005). Most of the environmental certifications utilize third-party verification. Thereby, NGOs, scientists and environmentalists design standards and practices alongside industry actors (Cashore *et al.*, 2004; Cheyns, 2011; Gereffi *et al.*, 2001; Hatanaka *et al.*, 2005). Yet, challenges have existed for achieving large impacts, suggesting not only further care in program design and implementation but also a rigorous evaluation of whether impacts arose.

One challenge is that many standards consider production processes, i.e., what the producers did, rather than qualities of outputs that result or specific impacts of the processes such as on nature, creating issues of transparency (Dankers & Liu, 2003). Standards aim to assess things including sustainability, biodiversity, ecosystems, absence of chemical fertilizers and pesticides, quality management, and sociopolitical attributes such as labor and indigenous outcomes (Badgley *et al.*, 2007; Bear & Eden, 2008; Klooster, 2010). Yet, this may present difficulties in measuring the outcomes, or associating them with certification. Many schemes also remain limited in spatial scope. These can make it more difficult to link such schemes with observed differences in, for instance, regional forests and fisheries (Ebeling & Yasué, 2009; Rametsteiner & Simula, 2003).

One additional challenge is to avoid marginalization of smaller producers. Standards developed for large-scale producers or consumer preferences in 'northern' countries may be difficult to apply within small-scale or developing contexts (Foley & McCay, 2014; González & Nigh, 2005). Complex standards may impose requirements that are harder for small-scale producers (Selfa *et al.*, 2014; Tovar *et al.*, 2005), who may not participate in shaping them (Cheyns, 2014; Köhne, 2014; Vandergeest, 2007). There may be costs that smaller-scale and developing country producers with limited capital cannot cover (Clark & Martínez, 2016; Pérez-Ramírez *et al.*, 2012). Their costs may even be higher (Blackman & Rivera, 2011; Lyngbaek *et al.*, 2001; Oosterveer *et al.*, 2014) yet in some cases, they receive political or social support (Quaedvlieg *et al.*, 2014).

Another challenge is to balance rigor and transparency in rule-making process and accessibility (Bush *et al.*, 2013). Legitimacy is often constructed through processes that are open and democratic and incorporate inputs from a variety of actors, including industry stakeholders. That could, however, generate a concern about businesses asserting their interests to the detriment of others (Eden, 2009; Hatanaka *et al.*, 2005; Havice & Iles, 2015; Klooster, 2010). Further, if schemes tend to expand, including in competition among schemes, stringency of such standards could be driven down (McDermott, 2012; Mutersbaugh, 2005; Taylor, 2005). In addition, there may be confusion induced by the presence of multiple such schemes, including industry-led schemes that compete for clients with third-party schemes (Cashore *et al.*, 2007) and can generate situations in which the consumers may not fully understand what each certification label indicates (Bear & Eden, 2008; Yiridoe *et al.*, 2005).

Large-scale public standard setting may then help. For example, the US Lacey Act or the EU's FLEGT (Forest Law Environment, Governance and Trade Mechanism) aim to prevent imports of illegally harvested forest products. FLEGT's Voluntary Partnership Agreements (VPAs) are one effort, that emphasizes independent monitoring, to collaborate with partners in source countries. To improve forest governance, they involve non-state actors such as civil society organizations and the private sector in processes sometimes requiring reconciliation as well as consolidation of conflicting laws (Bollen & Ozinga, 2013). Each VPA includes a system to identify legal products and to license them for import to the EU – with capacity building to help partner countries set up the licensing scheme, enforce, and where necessary reform laws. Legal assurance systems (LAS) are to distinguish illegally produced forest products, with five elements: a definition of legal, in light of producing country laws; a traceability system; a system to verify compliance with the legality definition and traceability system; a licensing scheme; and independent audit capacity.

Guidance for implementation was sought via consultation with major wood-producing countries (Ghana, Cameroon, the Democratic Republic of the Congo, the Central African Forest Commission (COMIFAC), Malaysia, Indonesia and Vietnam) (Hajjar, 2015; Tegegne, 2016) and VPAs have been signed with Ghana, Cameroon, Central African Republic, Republic of Congo, Liberia and Indonesia – while six more countries have been in negotiations (Côte D'Ivoire, the Democratic Republic of the Congo, Gabon, Guyana, Honduras and Laos). Indonesia has done the most such licensing and monitoring, licensing timber and wood-product shipments to the EU and applying standards to shipments to other countries. Some countries that have not yet started such licensing have improved in transparency, while acquiring significant skills, knowledge, and capacities in terms of these FLEGT systems for sharing information, monitoring and traceability of timber.

If rights are not clear, respected, and enforced, certification's outcomes can look very different. Outcomes of the types of certification we considered above appear to depend on effective rights. Forest certification, such as by the Forest Stewardship Council (FSC), considers logging within concessions or communities with effective rights – such as collective *ejido* tenure in Mexico – granted by the state but not always strongly enforced). Studying FSC in Peru, Rico *et al.* (2017) find that where concessions exhibit lower deforestation than surrounding areas, suggesting some effective enforcement, certification had a small positive effect upon forest conditions. However, where concessions had more forest loss than outside, certification has not had significant effect. It also has none within Cameroon (Panlasigui *et al.*, 2018), where PAs do not fare better than outside, suggesting significant limits on forest enforcement. From these examples, it seems that effective rights enforcement complements certifications.

2.1.8 INDIRECT DRIVERS: GOVERNANCE – LOCAL COMMUNITY COORDINATION

Commons or collective property system arrangements are present across the globe in spite of the historical challenges and pressures. Today, they often retain some of their traditional meaning, as part of collective management arrangement of common-pool resources, yet they have responded to various changes. To an extent, awareness of our dependence upon common-pool resources has brought attention to the centrality of property regimes – and their overlaps – for issues including water governance, waste management, congestion, landscape management, and climate change.

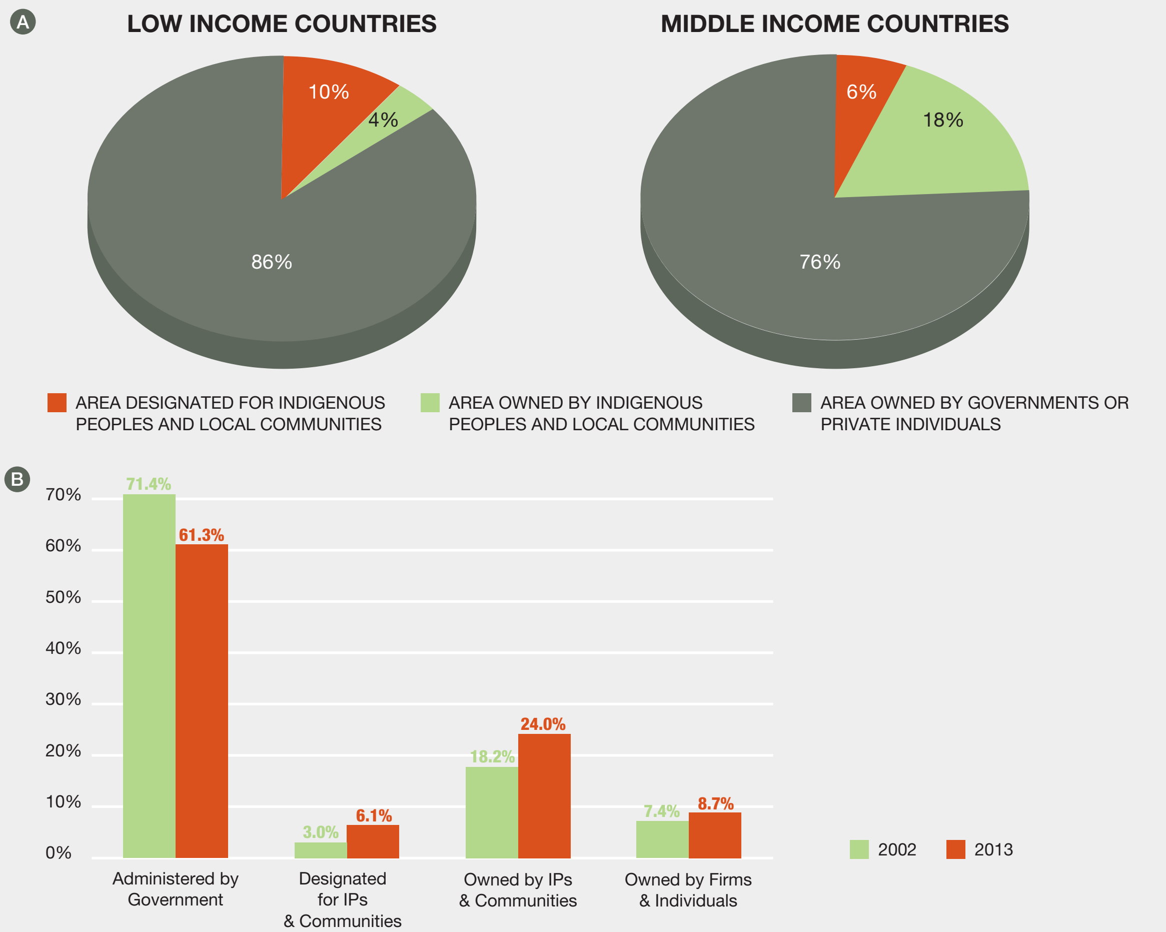


Figure 2 1 10 **"Recent status and temporal change for a number of categories of common land (versus other lands):**

A area under communal tenure regimes for low and middle income countries (including lower-middle and upper-middle income countries), and B % change in statutory forest land tenure in LMICs (low and middle income countries) from 2002 to 2013. Categories shown: area designated for Indigenous Peoples and Local Communities, area owned by Indigenous Peoples and Local Communities and the areas owned by governments or by private firms or individuals. Source: (RRI, 2014).

Historically, and currently in many regions of the world, rural land was owned and governed by local communities – a significant share under varied customary-property-regime arrangements (see chapter 1 for area estimates). State recognition of legal rights applies to only a fraction of the lands (Wall, 2014). Without recognition of legal land rights, many Indigenous Peoples and Local Communities are vulnerable to direct dispossessions and, thus, losses of livelihoods and culture. Customary property systems have often failed to stand up to external pressures related to colonization settlement, expansion of commodity production for agriculture, or forestry, mining, infrastructure extensions, government programs, and conservation programs.

Several international frameworks have tried to address these issues, including the International Labor Organization Convention 169 (ILO, 1989), UN Declaration on the Rights of Indigenous Peoples (UNDRIP), and FAO Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries, and Forests (VGGT) (FAO, 2012b). Also, in many regions communities have gained rights to land resources **(Figure 2.1.10)**, especially within Latin America (Agrawal *et al.*, 2008; Sunderlin *et al.*, 2008; White & Martin, 2002). Across developing countries, it has been estimated that around 27% of the forests are owned or designated for management by local communities, with rights to over 200 million hectares transferred (or just recognized) since 1985. In 2008, globally 24% of forests were owned by communities; 6% owned by governments but used by communities; 9% in private property; and 61% in public hands (Sunderlin *et al.*, 2008).

Securing collective rights and institutions has been considered as a key underlying component in sustained use and management, as communities change with external and internal circumstances (Ostrom, 2000). There are no statistically representative global analyses of effects on nature of community governance, yet there are observations from many case studies: e.g., using data from 80 cases of forest commons across Asia, Africa, and Latin America, Chhatre and Agrawal (2009) associated more local rule-making autonomy with higher carbon storage and livelihood benefits. This can occur because if the sustainability of a locally-relevant common-pool resource system is threatened, local resource users may invest to create new institutions to better local governance.

The recognition that local resource users sometimes craft effective governance has contributed to increased enthusiasm for the devolution of responsibilities to communities for the management of nature (seen within **Figure 2.1.10**). Community-based management after decentralization also can be successful (Amede *et al.*, 2007; Gibson *et al.*, 2005; Kearney *et al.*, 2007; Kellert *et al.*, 2000; Leach *et al.*, 1999; Ribot, 2004; Webb & Shivakoti, 2008) and merits additional understanding too. Further cases of common-pool resources suggest that – without privatization or nationalization – resource users do engage in collective actions to create local institutions to limit inefficient uses of natural resources, including in Indigenous Communities (Acheson, 1988; Baland & Platteau, 1996; Berkes, 1986; McKean, 1986; McKean & Cox, 1982; Ostrom, 1990; Poteete & Ostrom, 2004; Tang, 1992; Undargaa, 2017; Wade, 1988). Motivations for doing so can be clear when locals get direct resource benefits and, thus, are vulnerable to any unsustainable trends (Costanza *et al.*, 1998; Eerkens, 1999; Kelbessa, 2013; Ola-Adams, 1998; Shengji, 1993; Wade, 1988).

Indigenous Peoples and Local Communities have an advantage in designing local institutions, given knowledge of local ecological and social systems (Berkes *et al.*, 1998; Colding & Folke, 2001; Comberti *et al.*, 2015; Gadgil *et al.*, 1993; Nakashima *et al.*, 2012; Ostrom, 1990; Tang, 1994). Furthermore, as locals cross paths more frequently, they can monitor and enforce at lower costs, while also communicating expectations (Berkes, 1986; Ostrom, 1990) and imposing local social costs for violations of agreements. Also, without local participation in the crafting of such rules, constraints may lack legitimacy and credibility and, thereby, be inadequate for conservation (Costanza *et al.*, 1998).

Naturally, past governance institutions have not all been successful, and that reveals the roles of information, values, group size, boundaries, cultural and social homogeneity, and leadership that lowers transaction costs for interactions (Baland & Platteau, 1999; Ostrom, 1990; Wade, 1988). Learning across recent decades highlighted that critical contributions to nature, and livelihoods, have required shared norms, trust, and networks which can be developed through time and effort in reaching agreements (Agrawal, 2001; McKean, 1999; Meinzen-Dick, 2014; Pretty & Smith, 2004; Schlager & Ostrom, 1992). These have been limited by biophysical features, such as size and mobility (Becker & Ostrom, 1995; Schlager *et al.*, 1994), and social features like hierarchical heterogeneity and inequality, unless the well-endowed actors make substantial contributions (Andersson & Agrawal, 2011; Baland & Platteau, 1999; Blomquist, 1988; Dasgupta & Beard, 2007; Olson, 1965). Growing global demands also generate challenges (Agrawal & Yadama, 1997; Chhatre & Agrawal, 2008) with new markets establishing economic relationships lacking prior norms (Berkes *et al.*, 2006; Nietschmann, 1972; Richards, 1997; Smith *et al.*, 2010). For instance, historically, effective local marine regimes were far from market centers (Cinner, 2005; Cinner *et al.*, 2007), yet some institutions have responded to the payoffs from governance to confront even higher external market pressures (Alcorn & Lynch, 1994; Aswani, 1999, 2002; Bauer & Giles, 2002). That included state support of local collective rights which help to hold off commercial interests (Dupar & Badenoch, 2002; Pfaff & Robalino, 2017; Ribot, 2004; Richards, 1997) – while not being a panacea (Hinojosa, 2013).

Contributions to nature and livelihoods depend upon institutional details such as clarity of rights and congruence between such rules and the characteristics of the resource in question. Members of communities have responded better to such voluntary limitations when they have participated in rule design and modification, as well as when monitoring is linked to punishments. Sanctions have been better accepted when matching the seriousness of rule violations, and the context, with mechanisms for resolution of conflicts (Cox *et al.*, 2010). State legitimization of the processes helped (Koppen *et al.*, 2008) – but did not always occur (Bowles & Gintis, 2002; Cudney-Bueno & Basurto, 2009; Sarin, 1993; Utting, 1993; Young, 2001).

Interactions between local and non-local institutions have also mattered, because the ecosystems cross social and ecological scales (Armitage *et al.*, 2007; Berkes, 2008; Brown, 2003; Finkbeiner & Basurto, 2015; Hovik & Reitan, 2004; McKay, 2014). Fisheries provide examples of interactions between states and local institutions, with innovations over time. From the 1960s into the 1980s, small-scale fisheries were seen as failing to realize economic potential and food security (Berkes & Kislalioglu, 1989; Brainerd, 1989; Thompson, 1961), so governance should "rationalize this outdated sector" (Proude, 1973; Rack, 1962) by moving away from the "inefficient traditional practices". That guided aid (Basurto *et al.*, 2017) focused on raising production via improved technologies and infrastructure (World Bank, 2004). By the 1990s, after some notable collapses, over-exploitation became the focus for governance. Lack of rights (Campleman, 1973), mismanagement (Milich, 1999), destructive gear (Christensen, 2018), poverty and overpopulation (Pauly, 1997), urbanization, and globalization all were highlighted, alongside a lack of data. Large-scale offshore industrial catches competed with small fishermen, as well as governance aiming to restrict excess effort plus damaging methods such as trawls that scrape seabeds, longlines that trap seabirds, and non-selective nets that catch fish not consumed and damage protected species (Basurto *et al.*, 2017). This new framing shifted investment towards research on fish stocks (World Bank, 2014) and halted direct lending to fisheries for over a decade, until the World Bank re-entered with lending that was itself focused upon improving organization and governance.

2.1.9 INDIRECT DRIVERS: GOVERNANCE – STATES

2.1.9.1 Adjusting Development Policies

2.1.9.1.1 Property Rights & Resource-Use Rights

Property and resource-use rights, which depend at least in part on the state, affect outcomes for nature in many ways (Fenske, 2011; Platteau, 2000). Such rights arise through both formal and informal institutions, with *de jure* official rights and *de facto* effective rights present in different forms and combinations, and with varied impacts (Arnot *et al.*, 2011; Robinson *et al.*, 2018). Formal titling of land, for instance, is not always sufficient to promote either private investment or conservation (Holland *et al.*, 2017; Sills *et al.*, 2017). Evidence suggests that resource-tenure security is impacted by transport costs, for instance, and thus by distance: remote areas are harder to monitor and, hence, are more open to unsustainable harvesting and illegal invasion and harvesting (Albers & Robinson, 2013; Robinson *et al.*, 2008). Understanding these apparent trends in past impact can guide uses of rights within conservation.

Processes of establishing and defending rights are critical to outcomes for nature and wellbeing. One key process is decentralization, which is ongoing. Decentralization often transfers burdens of enforcing rights to local actors – agencies or users (Larson, 2002; Larson & Soto, 2008) – but sometimes also augments local property and resource-use rights (Coleman & Fleischman, 2012). Like rights in general, decentralization's net impact is specific to (quite variable) contexts, e.g., in Indonesia a recent effort affected forests and livelihoods as a function of many characteristics of communities (Sills *et al.*, 2017). In some settings, collective rights for groups may work better for conservation than do individual rights – although possibly overlapping with them (Baland & Platteau, 1999). Relative impact depends on the fraction of households with use rights, the area and profitability of forest, and species present (Alix-Garcia *et al.*, 2005; Baland & Platteau, 1996; Barsimantov, 2010; Baynes *et al.*, 2015; DiGiano *et al.*, 2013; Griscom *et al.*, 2009). Policy interactions also matter. Other policies such as recent agricultural subsidies and trade policy in Mexico, allowing timber imports from China, undermined domestic forestry profits and responses to collective rights (Ellis, 2014).

2.1.9.1.2 Transportation Investments (by context)

Economic development is influenced by the spatial pattern of roads, which lower transport costs. Globally, transport costs have fallen by ~40% across the last three decades, yielding aggregate economic growth as well as the spatial concentration of economic activity (World Bank, 2009). Highways have raised economic growth (Banerjee *et al.*, 2012; Bird & Straub, 2014; Storeygard, 2016), as well as total employment (Michaels, 2008) and industrial efficiency (Datta, 2012; Ghani *et al.*, 2016) – often, at least in part, through their impacts upon cities.

Some studies have focused upon past rural economic impacts of transport investments. Those are important for trading off with ecological impacts, such as the impacts of roads on forests, which often are higher at forest margins than in highly developed areas (Pfaff *et al.*, 2018). Studies find economic gains in agricultural productivity (Fan & Zhang, 2004; Zhang & Fan, 2004), reduction in poverty, and increased consumption (Asher & Novosad, 2016; Dercon *et al.*, 2009; Gibson & Rozelle, 2003; Khandker *et al.*, 2009) – plus labor shifts from agricultural to non-agricultural sectors (Asher & Novosad, 2016; Gollin & Rogerson, 2010). Another rural impact has been better access to credit and financial services (Binswanger *et al.*, 1993) – though we must allow that road placements often responded to other conditions, so causally identifying impacts can be difficult (Banerjee *et al.*, 2012; van de Walle, 2009). That restricts the quality of impacts evidence (Dulac, 2013; Khandker *et al.*, 2009).

Yet the apparent trends suggest important heterogeneity within economic impacts from transport. Roads have concentrated or dispersed economic activity, depending on the economic conditions. Cities connected to ports, or other cities, often benefitted more from trade and access to markets, as have rural areas along transport corridors, while unconnected rural areas have lost activities (Bird & Straub, 2014; Chandra & Thompson, 2000; Rephann & Isserman, 1994). In addition, labor will concentrate to earn higher wages stemming from economies of scale to human capital (World Bank, 2009). In Brazil, for instance, frontier roads have promoted settlement in many rural areas (Fearnside, 1987) yet, in those regions, urban population growth has been higher than rural rates. In India, given extensively settled rural areas new roads led people into cities (Asher & Novosad, 2016). When considering policy to balance multiple SDGs, the varied trends by context are key.

Transport investments – and in particular roads investments, which differ in impacts from rail – also, have driven large ecosystem losses. Early studies of road impacts mostly considered some economically less developed settings or “frontier” forests (Chomitz & Gray, 1996; Cropper *et al.*, 2001; Nelson & Hellerstein, 1997; Pfaff, 1999). For that broad context, roads expanded the areas where agriculture is profitable, causing further deforestation in the absence of institutional or policy constraints. Such study of deforestation impacts is summarized in reviews (Angelsen & Kaimowitz, 1999; Ferretti-Gallon & Busch, 2014; Geist & Lambin, 2002; Rudel *et al.*, 2009a). Others have summarized trends in how roads affect wildlife and ecosystems (Forman & Alexander, 1998; Laurance *et al.*, 2009). Many authors warn that expected global investments, up to 25 million kilometers by 2050, will surely exacerbate such ecosystem losses (Caro *et al.*, 2014; Laurance *et al.*, 2014, 2015).

Yet the magnitudes and even the signs or directions of transport investments’ impacts varied by: the types of roads; the stage of prior economic development; and economic activities involved (Mertens *et al.*, 2002; Pfaff *et al.*, 2016). While the stories that have dominated the literature and consciousness, including studies of large tracts of undisturbed forest with minimal property rights (Ferretti-Gallon & Busch, 2014; Rudel *et al.*, 2009a), on average suggest potential for high impacts, studies of actual variation in past impacts show that with high prior development, road-induced deforestation is actually lower (Andersen *et al.*, 2002; Pfaff *et al.*, 2007). These trends are suggestive of ways to limit deforestation by confining new transport to existing developed areas (Laurance *et al.*, 2014; Pfaff *et al.*, 2016). In extensively settled, non-frontier areas, for example in India and China, roads investments have even lowered deforestation, if roads encouraged the transition from agricultural to urban sectors (Deng *et al.*, 2011; Kaczan, 2016) and to plantations (Deng *et al.*, 2011; Kaczan, 2016).

2.1.9.1.3 Subsidies to Fuels

Subsidies to fossil fuels have been highly prevalent at least across recent decades, featuring both frequency across space and persistence over time, and all of that in spite of quite enormous costs. The International Monetary Fund states a cost of US$5 trillion – including the externality cost of nature’s degradation – with coal accounting for 52% of post-tax subsidies, petroleum for 33% and natural gas for 10% (Coady *et al.*, 2015). Davis (2016) estimates that there have been US$44 billion just in direct costs from carbon dioxide emissions, alongside traffic congestion, local pollution and also accidents – while noting that the subsidies have greatly reduced relevant actors’ incentives for generating clean innovations. Davis (2014) estimates additional large costs of ‘deadweight loss’ even without any environmental costs.

By all accounts, however, it has been significantly (and persistently) difficult to eliminate these policies that are ‘lose-lose’ in the sense of a worse environment and worse economic efficiency. That seems to be due to enormous public opposition concerning the possibility of their removal, including by affected groups and those advocating on behalf of the poor. However, it was shown that putting into practice a classic adjustment from economics textbooks could actually separate equity concerns from the enormous efficiency losses: cash transfers to the poor can compensate for price rises within any reform to improve key incentives (e.g., Salehi-Isfahani, 2016 on Iran).

2.1.9.2 Increasing Conservation Policies

2.1.9.2.1 Protected Areas and IPLC Lands/Participation

Governments have long created protected areas (PAs) to limit activities imperiling conservation. On the order of 15% of terrestrial and freshwater environments and ~7% of the marine realm are under some form of protection (UNEP-WCMC & IUCN, 2016), making protection the leading strategy to date for conserving biodiversity and ecosystem services. Protected areas were developed to preserve wilderness areas (Ervin *et al.*, 2010; Rodrigues *et al.*, 2004). However, the historically top-down approach to protection has evolved towards more inclusive conservation approaches (Berkes, 2010) – with protection categories ranging from strict (I–IV) to sustainable use (V–VI) (Dudley, 2008). The latter category includes "multiple-use" areas, which sometimes have bottom-up origins (Pfaff & Robalino, 2017). Recent decades saw considerable expansions, globally, in PA numbers and area (UNEP-WCMC & IUCN, 2016). Category VI grew most and it is the largest at ~40% of total PA area, though stricter top-down categories II and IV make up ~27% and ~13% (Juffe-Bignoli *et al.*, 2014), respectively. Also, the distribution of protection is not equal across the regions of the globe. For instance, one quarter of the terrestrial regions and over one half of marine regions are under 5% protected (Butchart *et al.*, 2012; UNEP-WCMC & IUCN, 2016).

Challenges for very significant impacts from PAs, though, arise in both enforcement and siting. Deforestation does occur within PAs, although usually at lower rates relative to the PAs' surroundings, indicating imperfect enforcement (at least for strict PAs), with losses of biodiversity and other services (Coad *et al.*, 2015). Enforcement clearly is critical. Also, it is not always better in strict PAs (Albers, 2010; Ferraro *et al.*, 2013; Fox *et al.*, 2012; Laurance *et al.*, 2012; Nolte *et al.*, 2013). Restrictive marine PAs, which are managed by states, have been effective within countries which have stronger legal frameworks. Bottom-up approaches can require community leadership to succeed, plus support from NGOs and private entities (Jones *et al.*, 2013). They may succeed in part due to lower monitoring costs.

Protected areas have had greater impacts when they effectively limited higher resource pressures. Where pressures are low, PA outcomes may be similar to their surroundings, i.e., impacts can be low and even zero when outcomes are undistinguishable from similar unprotected landscapes (Joppa & Pfaff, 2010; Nelson *et al.*, 2010; Pfaff *et al.*, 2009). One clear reason PAs are in lower-pressure sites is that local actors push back against protection, as they see PAs as a source only of local costs. This is less the case for multiple-use PAs which, depending on locations and enforcement, can have more impact (Nelson & Chomitz, 2011; Pfaff *et al.*, 2014). If PA impacts are higher under pressure, that suggests integration of protection with regional development (Mora & Sale, 2011; Stoll-kleemann *et al.*, 2006), e.g., siting the PAs alongside new roads (Pfaff *et al.*, 2015a, 2015b) and optimizing road siting with impacts on nature and economies in mind (Andam *et al.*, 2010). PAs often imply local cost but also can offer local tourism benefit (Andam *et al.*, 2010; Robalino & Villalobos, 2015).

Indigenous Peoples and Local Communities have long protected, and currently conserve, many ecosystems (see chapter 2.2) and indigenous lands have often had consequential impacts, sometimes more than nearby PAs. Many IPLC approaches to conservation have been scaled up, yet opportunities for participation in global and national policy processes have been limited for IPLCs, although increasing in international organizations such as the CBD. Participation in national biodiversity strategies and action plans (NBSAPs) has been limited to date, with country exceptions. Since 2004, numerous IPLCs have identified concrete actions for adding important principles into national policies and programs for sustainable use of biological diversity (Forest Peoples Programme, 2011), e.g., the Plan of Action on Customary Sustainable Use (adopted in 2014). Many IPLCs are determined to play an active role in implementing this Plan through 2020 and well beyond. For example, a global indigenous coalition from the Amazon, Central America, the Congo Basin and Indonesia pledged to protect 400 million ha of forests (LPAA, 2014) and the Palangka Raya Declaration on Deforestation and Rights of Forest Peoples has concrete policy recommendations to address habitat loss (Forest Peoples Programme, 2014). Amazonian Kayapo people in Brazil are conserving 105,000 km^2 of forests in a frontier characterized by heavy deforestation due to agriculture and pasture expansion, illegal gold miners, logging and infrastructure. They also led (unsuccessful) pressures on the World Bank and other international financing institutions to stop loans for a mega-dam on the Rio Xingu (Zimmerman, 2010). In Kapuas Hulu (West Kalimantan, Indonesia) indigenous Dayak peoples contribute to conserving forest, river and lake habitats that are under threat from oil palm (Colchester *et al.*, 2014; Porter-Bolland *et al.*, 2012).

Given this history, and mixed trends, policymakers and scholars are reconsidering roles of local communities in the context of expansions of both resource use and conservation. Communities' rights have been shown to generate incentives for local protection, monitoring, and enforcement (Berkes *et al.*, 2006). Empowered local fishers have been seen to be more likely to comply with regulations (Bennett & Dearden, 2014). Indigenous and local knowledge, including from women (Agarwal, 2009), has aided conservation success (Brooks *et al.*, 2012; Jones *et al.*, 2013; Stoll-kleemann *et al.*, 2006). Policies that do not undermine local ownership but instead guarantee local involvement in all of design, implementation and benefits (Bennett & Dearden, 2014) have contributed to conservation, as peoples understand their livelihoods depend on maintenance of the environment including via strong organizational and technical capabilities within rural communities (Sim & Hilmi, 1987). Many forests and other biodiverse habitats are within IPLCs' lands and territories (FPP *et al.*, 2016), overlapping areas of high biodiversity and biocultural diversity (Sobrevila, 2008; Toledo, 2013). Yet, there are still limited data about local farmers' and livestock keepers' relations to genetic diversity, in particular for species with cultural or economic values, such as traditional medicines or non-timber forest products (CBD, 2014).

2.1.9.2.2 Payments for Ecosystem Services and Other Incentives

On private lands, payments for ecosystem services (PES) offer compensation for the voluntary acceptance of restrictions to reduce degradation, such as shifts in land uses or polluting practices. PES are conditional on beneficial actions or outcomes. Thus, they generate incentives for voluntary provision of ecosystem services by varied private actors (see also chapters 3 and 6). Payments are made by other private actors (Coase, 1960) or by states, as representatives (Ferraro & Kiss, 2002), based on outcomes like standing forests or related practices (Sattler & Matzdorf, 2013). To date, most PES schemes have used action-based rather than result-based conditionality (Engel *et al.*, 2008; FAO, 2007), if they actually use conditions for payment at all (Ezzine-de-Blas *et al.*, 2016). The payments approach makes sense when the buyers' willingness to pay is above sellers' opportunity costs – else those providers would not supply ES (Nelson *et al.*, 2008; Perrot-Maître, 2006). These payments aim to align private goals with social goals (Dobbs & Pretty, 2008; Muradian *et al.*, 2010). Governments may use them alongside PAs to lower local costs and spillovers, relative to pure mandates alone. For multiple-use PAs, that could even involve providing PES inside PAs – which *de facto* can yield additionality if restrictions alone were being rejected (see Tuanmu *et al.*, 2016 for Wolong in China).

To date, though, PES additional impacts beyond baseline are not so encouraging. PES often have been implemented where opportunity costs are medium to low (Tacconi, 2012), just as for PAs, albeit in this case driven more by private decisions about which lands to volunteer for inclusion. Because information about opportunity costs is private, PES designers face a challenge (Börner *et al.*, 2016; Hejnowicz *et al.*, 2014; Sattler & Matzdorf, 2013), since actors with low profits from clearing forests more frequently volunteer to accept a payment for leaving lands in forest. Thus, payments for standing forest have had limited impacts. Studies suggest low impacts of PES (Robalino & Pfaff, 2013 for Costa Rica). Efficient impact may require targeting. Yet, if a service is a priority, e.g., if drinking water or the electricity from hydropower are scarce (Brouwer *et al.*, 2010), then actors have targeted influential lands upstream of dams or cities and utilized higher payments to overcome competing pressures. When a service such as clean water is an input to a good with economic importance (e.g., soda or beer), again targeting and payment sometimes are higher. Further, some designs could help states to reveal private opportunity cost (Ajayi *et al.*, 2012; Ferraro, 2008; Polasky *et al.*, 2014 using auctions; Sheriff *et al.*, 2009 using observable data) and how resulting surpluses are shared is important, while some authors have shown that not differentiating payments between regions has efficiency losses (Ezzine-de-Blas & Dutilly, 2017; Lewis & Plantinga, 2007; Lewis *et al.*, 2009, for instance consider fragmentation). In China, while 'PES' were perhaps less voluntary, as the state prioritized large areas per flood risks, the compensation appeared to cover local opportunity costs (Uchida *et al.*, 2007). In some settings in Europe and in the US, large PES seemed to align with private sector goals of transitions in production to ecologically friendly systems, yet market actors may want assurance about permanence. Other challenges include the need to target only some participants, without triggering negative fairness reactions (Alpízar & Cárdenas, 2016; Mercado *et al.*, 2017).

One way to raise the incentives for ecosystem services suppliers is to allow multiple ecosystem services to be sold on the basis of a single shift in land use. In Bolivia, for instance, *Acuerdos Reciprocos por El Agua* yielded both water and biodiversity outcomes (Wunder & Albán, 2008). Payment for one service does not, then, offer the socially efficient 'price' to align the incentives. Private actors should face incentives based on all of the ecosystem-service gains due to their acts. Thus 'stacking', or suppliers receiving a separate payment for each service, can be more socially efficient for PES programs – although not for all regulatory structures (Pfaff & Robalino, 2017).

Another challenge has been uncertainties, given variations in species or other ecosystem-service benefits across locations. Planners may wish to target an ecosystem service, yet monitoring could involve high costs. Hily & Gégout (2016) study PES designs with unobserved costs and benefits which could be considered for biodiversity conservation policy – alongside PAs plus regulations like the Natura 2000 (N2K) policy that covers 18% of the EU's terrestrial surface (or, generally, "command-and-control" like the EU's Habitats Directive and the US Endangered Species Act). Incentives-based contracts for biodiversity conservation in forests have been implemented in EU states including Denmark, Germany and Slovakia (Anthon *et al.*, 2010; Ecochard *et al.*, 2017). Hanley *et al.* (2012) and de Vries and Hanley (2016) review studies of incentives for biodiversity with varied costs and benefits from conservation, hidden information (asymmetric across actors such as their private costs), and stochastic elements as well (Armsworth *et al.*, 2012). Targeting based on costs and benefits has been suggested (Babcock *et al.*, 1997; Duke *et al.*, 2013; Naidoo *et al.*, 2006). Experiences have showed that an understanding that allows planning around such heterogeneity allows gains (Bamière *et al.*, 2013, for example, compare an auction to a uniform subsidy in order to reach a specific configuration of lands). Auctions have been investigated (Fooks *et al.*, 2015; Schilizzi & Latacz-Lohmann, 2007) that consider not only costs but also benefit-cost ratios (Che, 1993; Latacz-Lohmann & der Hamsvoort, 1997). The efficiency from targeted auctions depends on the relative variability of costs and benefits, as well as their correlation (Ferraro, 2003), however, and any implementation assumes states have accurate knowledge, which may not hold for biodiversity.

For this domain, once again policies have considered collectives, or groups, attempting to apply lessons from common property settings, as 27% of forests in developing countries are under collective title and this percentage may increase with devolution (Agrawal *et al.*, 2008; Molnar *et al.*, 2011). Private rights and state enforcement have not always succeeded (Dietz *et al.*, 2003). Positive group examples exist for: forests (Pagdee *et al.*, 2006); irrigation infrastructure (Wade, 1985); fisheries (Acheson, 1988; Feeney *et al.*, 1990); and pasture (Moritz *et al.*, 2013). Communication and trust are key elements (Hackett *et al.*, 1994; Ostrom, 2000; Pretty, 2003). Inequality hinders collaboration and participation, yet gains are lower for the socioeconomically disadvantaged (Agrawal & Gupta, 2005; Kumar, 2002). In PES for collective titles and decision making (Hayes *et al.*, 2017; Kerr *et al.*, 2014), i.e., when contracting with groups of relevant landholders, responsibilities and rewards are collective and communities motivate members using internal governance to address challenges such as free-riding. A limited literature suggests collective PES could help in rule setting (Hayes *et al.*, 2015, 2017), attitudes towards rules (Sommerville *et al.*, 2010), and, ultimately, sustainable resource use (Clements *et al.*, 2010) – especially when local actors are involved in the designs of programs (Cavalcanti *et al.*, 2010; Kaczan *et al.*, 2017; Walker *et al.*, 2000).

Pre-existing collective arrangements have been important in PES, leveraging members' existing collective motivations (Muradian, 2013; Muradian *et al.*, 2010; Porras *et al.*, 2008), and facilitating the coordination with intermediaries (Jack *et al.*, 2008). Collective contracts can help due to lower per-participant costs, given economies of scale in monitoring (Kaczan *et al.*, 2017) and lower transactions costs with fewer large contracts (Kerr *et al.*, 2014). Also, in terms of ecosystem-service benefits, contracts which cover larger areas can of habitat can match needs of species (Swallow & Meinzen-Dick, 2009).

Collective contracting could face a challenge when sanctions are required to enforce compliance, as has become apparent for "non-point" emissions, where emissions cannot be linked to people due to monitoring costs. While schemes exist if only aggregate pollution is measured (Alpízar *et al.*, 2004; Cason & Gangadharan, 2013; Cochard *et al.*, 2005; Poe *et al.*, 2004; Segerson, 1988; Spraggon, 2002, 2004; Vossler *et al.*, 2007; Xepapadeas, 1991) in practice they are not adopted – partially due to a lack of fairness, as people are punished for others' acts. Yet such an approach can work with strong collective function (Kaczan *et al.*, 2017).

2.1.9.2.3 Choosing Policy Instruments

Many instruments have been used to either support or regulate activities that affect nature, both incentives and restrictions. For instance, current policy debates consider a carbon tax (a "price") which does not dictate a specific process or technology, as well as restrictions on level of output. When quantities have been restricted, sometimes "cap-and-trade" regulations have started with a limit – e.g., on total fish extracted or total emissions – that is broken up into individual limits, which individual actors are allowed to trade flexibly among each other. Firms that innovate need fewer emissions permits and, thus, could sell permits to other firms – creating an incentive to innovate.

While the implementation of these kinds of policies has often assumed 'perfect information', a fundamental challenge arises with various types of uncertainty and other deficient information. Weitzman (1974) considered uncertainty in regulations' costs and benefits, finding that the best policies considered relative sensitivity of the costs and the benefits. A cap policy allowed costs to vary, while a price policy (via a tax) allows amounts, e.g., emissions to vary. Thus, when the benefits of regulations are very sensitive at a threshold, it has been deemed better to be sure of quantities through caps (using trading for cost flexibility). However, if regulations' costs were sensitive, as is the economy, it has been deemed better to keep a handle on the costs, by using taxes. This has all been applied for different uncertainties (Fishelson, 1976; Stranlund & Ben-Haim, 2008; Yohe, 1978) and non-linearities in costs and benefits (Kelly, 2005; Yohe, 1978).

2.1.9.3 Equity Considerations

2.1.9.3.1 Wealth-based and Race-based Differences

Equity is an important, yet complex aspect of policy related to economic development and nature. For regulations like emissions limits, with permits trading for efficiency, distributional outcomes have varied greatly (Bento, 2013; OECD, 2006). For instance, regulations may unequally burden low income laborers – who face additional effects if firms shift into capital (Fullerton & Heutel, 2007; Fullerton & Monti, 2013), or employment shifts sectors (Bento, 2013), such as in the US post-1970s due to the Clean Air Act (Greenstone, 2002; Walker, 2013). Political implications of policy costs draw increasing attention (Bento, 2013; Bento *et al.*, 2005; Fullerton, 2011; Kolstad, 2014; Parry *et al.*, 2006; Pizer & Sexton, 2017). Looking ahead, based upon past efforts, policy revenues from pollution taxes or auctions of permits may invested in reducing other taxes (Bento & Jacobsen, 2007; Dinan, 2012; Metcalf, 1999, 2008; Parry, 1995; "revenue recycling" in Poterba, 1991b) or in tax credits or specific programs for lower-income households.

In evaluating equity implications of the environment policies put into place during past decades, challenges remain for calculating benefits and costs. First, willingness to pay by citizens is hard to know, although the lower-income households seem less willing to pay due to limited income. Second, heterogeneous behavioural responses generated heterogeneous impact from policies, e.g., changes in exposure risks, even if policy was "provided equally" (Bento, 2013; OECD, 2006).

Trade-offs based on heterogeneities across actors also arise when a few small producers are more efficient, putting efficiency and equity in tension (Birkenbach *et al.*, 2017; Brandt, 2005; Brinson & Thunberg, 2016; Da-Rocha & Sempere, 2017; Grafton *et al.*, 2000; Homans & Wilen, 2005; Olson, 2011). Transferable fishing quotas (ITQ) have offered examples, as efficiency may be high if a fleet has fewer vessels – avoiding 'overcapitalization' – yet that favours large industrial producers over artisans. Small-scale

Box 2 1 3 United States, examples of inequalities in exposures to environmental quality.

Scholars have illustrated equity issues concerning, for example, chemical facilities' toxic emissions (Ash & Fetter, 2004; Mohai *et al.*, 2009) and cumulative health risks from multiple pollutants (Morello-Frosch & Shenassa, 2006; Morello-Frosch *et al.*, 2011; Sadd *et al.*, 2011; Su *et al.*, 2009), as well as for environmental amenities, such as grocery stores and more healthful foods (Hilmers *et al.*, 2012; Morland *et al.*, 2002), parks (Boone *et al.*, 2009; Sister *et al.*, 2010), and overall tree cover (Heynen *et al.*, 2006; Landry & Chakraborty, 2009; Schwarz *et al.*, 2015).

There are debates over how best to document disparities, for risks and amenities (Chakraborty *et al.*, 2011; Mohai *et al.*, 2009; Mohai & Saha, 2006), yet race- and income- and wealth-based disparities appear to have persisted in varied forms. Crowder & Downey (2010) found that, at neighborhood level, black and Latino households were more likely to experience high levels of proximate industrial pollution – and across levels of income. Varied case studies document communities' struggles against lead smelters (Bullard, 2000), toxic chemical facilities (Purifoy, 2013), concentrated animal feed operations (Wing *et al.*, 2000), oil refineries (Lerner & Bullard, 2006) and cumulative impacts from multiple polluters (Sze, 2007).

As exposures are based on location, this raises locational segregations by race as well as wealth and, thereby, the legacy of racially-based housing (Katznelson, 2005; Lipsitz, 2006; Satter, 2009) and residential policies based on house type and lot size (Meyers, 2003; Nelson, 1996). As race corresponds with wealth, segregation is apparent, including as per discriminatory residential steering practices within real-estate (Bullard *et al.*, 2007; Ford, 1994). Some degree of immobility is central within exposure inequity, with race and wealth limiting options (Aiken, 1985; Jepson, 2012; Mills, 1997), since wealth disparities are a self-reinforcing feature that limits the mobility of minorities (Bullard, 2007; Darity *et al.*, 2006; Oliver & Shapiro, 2006). Poorer families might well, then, make rational choices to face higher pollution, so as to lower their costs, given lower incomes. Further, adding resource amenities or reducing environmental dis-amenities, which yields higher rents, could help local owners but hurt renters.

Unequal exposures over space and groups can be due to public choices, for instance in the US for communities struggling against hazardous waste incinerators and dumpsites (Bullard, 2000; Cole & Foster, 2001) and solid waste facilities (Pellow, 2004). Public zoning choices interact with immobility if the dis-amenities drive out those who can afford to move (Silver, 2007; Taylor, 2014), although political inclusion in environmental decisions is a core plank of environmental justice – indeed the definition of environmental justice for the USA Environmental Protection Agency (EPA) is: "fair treatment and meaningful involvement of all people, regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies" (US Environmental Protection Agency, 2016, 2018). However, in considering the past trends in placements of dis-amenities, the EPA failed to issue a single finding of racial discrimination in the permitting of hazardous facilities under the Civil Rights Act (US Environmental Protection Agency, 2016). Thus, even explicit statements do not guarantee political inclusion.

Post the Civil-Rights-era, policies also advance "color-blind racism" (Bonilla-Silva, 2010) using seemingly race-neutral terms such as 'multifamily' or 'subsidized' (Morris, 1997). A California report suggests those least likely to resist waste-to-energy facilities: low income; high school or less education; and open to promises of economic benefits (Cerrell Associates & Powell, 1984). This maintains disparities (Bonilla-Silva, 2010). It seems such inequities may be shaped by broader mechanisms, e.g., those underlying mass incarcerations (Agnew, 2016; Brown *et al.*, 2016; Gilmore, 2007; McKittrick & Woods, 2007; Pellow, 2016; Woods, 1998).

fishers or vessel owners may simply sell and exit, lowering welfare in lower-income communities (Carothers *et al.*, 2010; Olson, 2011; Stewart & Walshe, 2008). Fewer vessels could also lower employment, although extended fishing seasons could increase the total hours worked, increasing the overall wage bill. Consolidation of production within a few larger firms also impacts many shore-side firms as well as employment within the processing sector (Abbott *et al.*, 2010; Anderson *et al.*, 2011; Birkenbach *et al.*, 2017; Brandt, 2005; Copes & Charles, 2004; Olson, 2011). To address this, states have in some cases restricted the transfers of fish permits, reducing efficiency gain (Da-Rocha & Sempere, 2017; Grafton *et al.*, 2000; Kroetz *et al.*, 2015).

Moving to environmental quality and exposures, some example of outcomes have illustrated the issue of unequal distributions of environmental burden, one present in many parts of the world.

2.1.9.3.2 Policy Responses (rights, subsidies)

In fisheries and forests, public restrictions on extraction have been shown to have the capacity to help efficiently trade-off nature and individuals' basic needs. Extending to individual actors can further increase efficiency and address equity too. A lack of agreed rights and restrictions in, e.g., open-access fisheries, have been showed to be responsible for dissipation of economic rents and degradation of stocks (Caddy & Cochrane, 2001; Charles, 1988; Gordon, 1954; Kronbak, 2014). On a global scale, those fisheries harvested by multiple countries are more likely to be degraded (McWhinnie, 2009), while exclusive economic zones to exclude foreign fishers are a response. Economic costs of misaligned incentives are over $80 billion annually (Kelleher *et al.*, 2009), including from misallocations of labor and capital (Homans & Wilen, 2005; Kelleher *et al.*, 2009; Manning *et al.*, 2018; McElroy, 1991; Pauly *et al.*, 2002). Restricting effort or gear lowers inefficiencies – but all individuals must be limited or rents get dissipated and inequity arises (Homans & Wilen, 1997; Wilen, 2006). If regulators close access after a fixed total harvest, instead of fixing individual rights, then fishers will race (Birkenbach *et al.*, 2017) with costs (Grafton, 1996; Huang & Smith, 2014) and risks (Pfeiffer & Gratz, 2016).

Individual fishing quotas (IFQs) or catch shares reduced costs of racing by offering more secure shares of total allowable catch (TAC). Catch-share systems have grown since the 1970s (Christy, 1973) in part because exclusive economic zones made it possible for regulators to restrict access (Costello *et al.*, 2010; Tveteras *et al.*, 2011). Shares give fishers a stake in the health of a fishery and may lower collapse (Costello *et al.*, 2008; Essington *et al.*, 2012; Melnychuk *et al.*, 2012). For a non-mobile fish species, one variant is "Territorial Use Rights for Fisheries" (TURFs), which give a specific harvester exclusive access to an area (Wilen *et al.*, 2012). Incentives issues and fairness issues still arise (Abbott *et al.*, 2010; Bromley, 2009; Grimm *et al.*, 2012; Kristofersson & Rickertsen, 2009). Some may be addressed by property rights for collectives, as found in small-scale fisheries (Acheson, 1988; Basurto *et al.*, 2012; Feeney *et al.*, 1990; Leal, 1998), which produce half of the total global fish harvest (Jacquet & Pauly, 2008). One way or another, though, all such decisions about rights allocations have equity implications.

Another response to marine equity issues is subsidies, raising equity and efficiency issues just as for fossil fuels (CWN'18/10). *The Sunken Billions* (FAO, 2009c) has estimated total global rents from marine fisheries and found that overfishing lost US$51 billion in rents in 2004 (supported by Sumaila *et al.*, 2012). An update found losses of US$83 billion in 2012 (World Bank, 2017a) These figures suggest that in some areas rents were negative, i.e., revenues did not cover costs, necessitating subsidies for firms to continue (World Bank, 2018o). Despite data limitations, such results clearly suggest widespread overfishing and declining fish stocks, i.e., huge inefficiencies likely to involve and lead to inequities if limitations are then extended.

Any limitation on communities' extraction rights is a significant equity concern for the IPLCs, including in the context of trade that responds to national differences in the rights for resources (Chichilnisky, 1994; Krausmann *et al.*, 2009). Affluent 'Global North' industrialized countries import from resource-rich countries in the 'Global South', where stocks have fallen (Garmendia *et al.*, 2016)but states often capture little surplus. Martínez-Alier (2002) notes 'ecological debt' to the South, referencing varied inequalities over time within such exchanges relevant for nature (while here we focus upon the rights issues underlying inequities, this links to 'grabbing' above).

Indigenous Peoples, in particular, have highlighted threats from petroleum and mining activities, which were authorized and incentivized by national governments, as in Ecuador (Forest Peoples Programme, 2007). Mining's threats to the food security of Indigenous Peoples were seen in the Philippines (Working Group on Mining in the Philippines, 2009). Violent confrontations have occurred, e.g., an incident occurred in 2009 in Peru after a lack of consent by Indigenous Peoples for petroleum firms to enter indigenous territories. Indigenous Peoples in Latin America, Asia, and Africa are not categorically opposed to mining – although they struggle to hold companies and governments accountable for the negative local impacts (Herbertson *et al.*, 2009; Richardson, 2007). Water contamination from mining, for instance, continues to stir up such heated conflicts (Anaya, 2011; Van de Wauw *et al.*, 2010; van der Sandt, 2009). In the Philippines alone, by one account, there were 800 extrajudicial killings. in the period 2001–

2006, associated with protests against mining (Doyle *et al.*, 2007).

2.1.9.3.3 Equity & Environmental/Energy Taxes (context dependence)

Equity impacts of taxes have varied across contexts, including by the type of commodity plus the physical, social and climatic characteristics. Relevant characteristics have included the transport infrastructure, housing stock, diffusion of technology, incomes, and patterns of work (Cronin *et al.*, 2017; Pizer & Sexton, 2017). In the UK, the share of households' budgets spent on natural gas falls with household total expenditure, since gas is used for heating. In this case, natural gas taxes are regressive, i.e., their burden falls more heavily on the poor. Yet, the budget shares for natural gas rise with household expenditure in Mexico – where there is less need for heating overall and less adoption of home-heating capital at lower incomes. Comparing the UK to the US, which has more similar incomes, due to climate the UK does less cooling – whereas air conditioning uses significant electricity in the US (less in coastal areas which also exhibit higher incomes). Mexico is warmer but its electricity budget shares are lower, with low air conditioning (Davis, 2014). In general, equity impacts depend upon use. Another example is the gasoline tax – which is progressive or neutral in the UK, yet regressive in the US because of more use by the poor with less use of public transit plus longer commutes.

Electricity taxes' direct effects have been regressive, for most settings, reflecting the importance of electricity. Much as for food and water, the expenditure shares decline with the income level. US households with lowest expenditures devote nearly 7% of their total spending to electricity, over three times the budget share for the wealthiest decile (Pizer & Sexton, 2017). In the UK, electricity budget shares decline from over 8% among the poorest households to barely 1% for the wealthiest. Likewise in Mexico, to a lesser degree (Pizer & Sexton, 2017). Flues & Thomas (2015) find electricity taxes to be regressive in 21 OECD countries based on expenditure shares.

Yet, energy and gasoline taxes tend not to be regressive in poorer countries, as vehicle ownership rates as well as commuting patterns matter greatly. Transportation-fuels taxes are thought to be progressive in Brazil, China, Costa Rica, Mexico, and Turkey, as well as in Chile and Hungary, where vehicle ownership differs across incomes by an order of magnitude (Flues & Thomas, 2015; Pizer & Sexton, 2017). In Ethiopia, modern transportation in any form is beyond the reach of the poorest households and, thus, a transportation-fuels tax is strongly progressive (Flues & Thomas, 2015; Sterner, 2012). Indirect effects of taxes, however, still sometimes have been regressive. For instance, diesel taxes raise the cost of public transport, which impacts the expenditures of low income people (Flues & Thomas, 2015; Pizer & Sexton, 2017). Yet overall, low income households have been less affected by the indirect impacts of energy taxes because they consume less (Hannon *et al.*, 1978; Herendeen *et al.*, 1981). Mass transit systems lower private vehicle use in Europe, where longer commutes in one's own vehicle are rare (Haghshenas & Vaziri, 2012; Stutzer & Frey, 2008). In contrast, in the US, lower-income people are likely to own automobiles and drive relatively long distances (Pizer & Sexton, 2017). Gasoline taxes even have had significant effects on economic growth (Hamilton, 2009; Kilian, 2008a, 2008b) – plus upon housing markets (Sexton *et al.*, 2012), in terms of both home construction (Molloy & Shan, 2013) and home price (Morris & Neill, 2014).

Finally, in terms of how such issues arise in official measurements, perceived regressivity falls if considering groups in terms of their consumption instead of expenditures, which fluctuate less – most likely as they track expected lifetime income (Poterba, 1991a). How one ranks households matters so much that: if calculating using income, fuel taxes in Germany and Sweden have been regressive; while using expenditures, it is the opposite. A challenge for addressing equity issues, then, is that expenditures can vary considerably across households which have the same income.

2.1.10 INDIRECT DRIVERS: GOVERNANCE – GLOBAL COORDINATION

"Global commons" often refers, loosely, to resources domains in which many countries interact, indicating shared natural resources such as the oceans, the atmosphere, outer space and the polar regions. According to the World Conservation Strategy (IUCN, 1980), in this common form of usage: "global commons includes those parts of the Earth's beyond national jurisdictions … the open ocean and the biodiversity it contains … or [parts] held in common, as the atmosphere and the Antarctica".

Global commons clearly merit attention, including specifically those domains with common-pool resources, which are rivalrous – i.e., one consumes at the expense of others – and for which it is costly to exclude potential users, e.g., when a resource is large and abundant, plus resource users are disconnected from each other. A leading challenge is the design of governance structures and management systems capable of addressing multiple public and private interests given resources with those characteristics. Mutually agreed mutual coercion is called for to avoid 'tragedy of the commons' at any level (Hardin, 1968; Ostrom, 1990).

Conditions can make global collective management easier or harder. For instance, resource scale, number of users, absence of a shared culture for resource users, and more heterogeneity globally than for local management of common-pool resources (Dietz *et al.*, 2003) all matter. Social learning about the resource dynamics and the implications of diverse uses is critical too.

Various global environmental protocols were deployed in the last 50 years, especially after the 1972 Stockholm Intergovernmental Conference. The Montreal Protocol to address the 'ozone hole', for instance, has become a reference for linking governments and the private sector and contributing to promote economic, technological, and behavioural changes. On the other hand, many legally binding protocols do not provide a full solution for global commons governance, since they are slow to be implemented, or lack either monitoring or enforcement capacity and activities. Patterns of adoption over time can be seen within **Figure 2.1.11**, by country income levels (also see Figure S16).

Some cooperation has involved aquatic ecosystems, including wetlands that reduce impacts of floods, coastal storms and high temperatures as an alternative to 'grey' or engineered solutions. Loss of wetlands to food production reduces flood protection and storm-water management, a tradeoff. Yet, nonetheless, one third of global mangrove ecosystems are depleted or severely degraded. In India, Philippines, Vietnam and the Americas they have been extensively cleared and overall the world has lost 50% of wetlands since 1900. Davidson (2014) review 189 reports of changes in wetlands, reporting average long-term losses of natural wetlands near 50%, since 1700, and as high as 87% – with rates of loss more than three times faster for inland wetlands. Facing such pressures, the Ramsar Convention on Wetlands of International Importance is one intergovernmental mechanism concerning wetlands protection globally. To date 169 countries participate, having designated over 2,200 wetlands of international importance (Ramsar Sites) which together cover an area of 215 million hectares, an area that is equivalent to the size of Mexico. Yet it remains uncertain whether these commitments by national governments to the Ramsar Convention have actually had impacts in significantly reducing rates of wetlands loss.

Other global agreements also concern water management, e.g., the Boundary Waters Treaty of 1909 set up mechanisms to resolve disputes over waters between the US and Canada, while the Helsinki Rules on Uses of the Waters of International Rivers of 1966 include recommendations for regulations when rivers and connected groundwater systems flow across national boundaries. Approved and adopted by International Law Association (ILA), this still lacks any enforcement.

Among 'global' coordination actions, we consider regional social systems and ecosystems, especially if they cross international boundaries. One example is the Johnston Agreement of 1955 concerning Israel, the West Bank, the Gaza Strip and Jordan, with conflict-resolution mechanisms regarding water scarcity. The Indus Waters Treaty of 1960 addresses water distribution between Pakistan and India. Regulatory authority for three "eastern" rivers (Beas, Ravi, Sutlej) was given to India, with the authority for three "western" rivers (Indus, Chenab and Jhelum) given to Pakistan and mechanisms for water sharing sketched out for sectors such as irrigation, transport and power generation. One global effort has been the Convention on the Protection and Use of Transboundary Watercourses and International Lakes – Water Convention – due to the United Nations Economic Commission for Europe. This entered into force in 1996, with 40 states and the European Union as parties and mandates to: improve states' efforts to shield and organize shared water systems and groundwater; and promote cooperation with joint decisions including governance with monitoring, research, consultations, warning systems and knowledge exchange.

Moving to the oceans, recognition of the International Council for the Exploration of the Sea as an expert body for the governance of marine resources occurred in 1928, while in 1945 the FAO was founded to identify and address key challenges to revitalizing the fisheries sector in Europe. Challenges were over-fishing and over-capacity. Regional

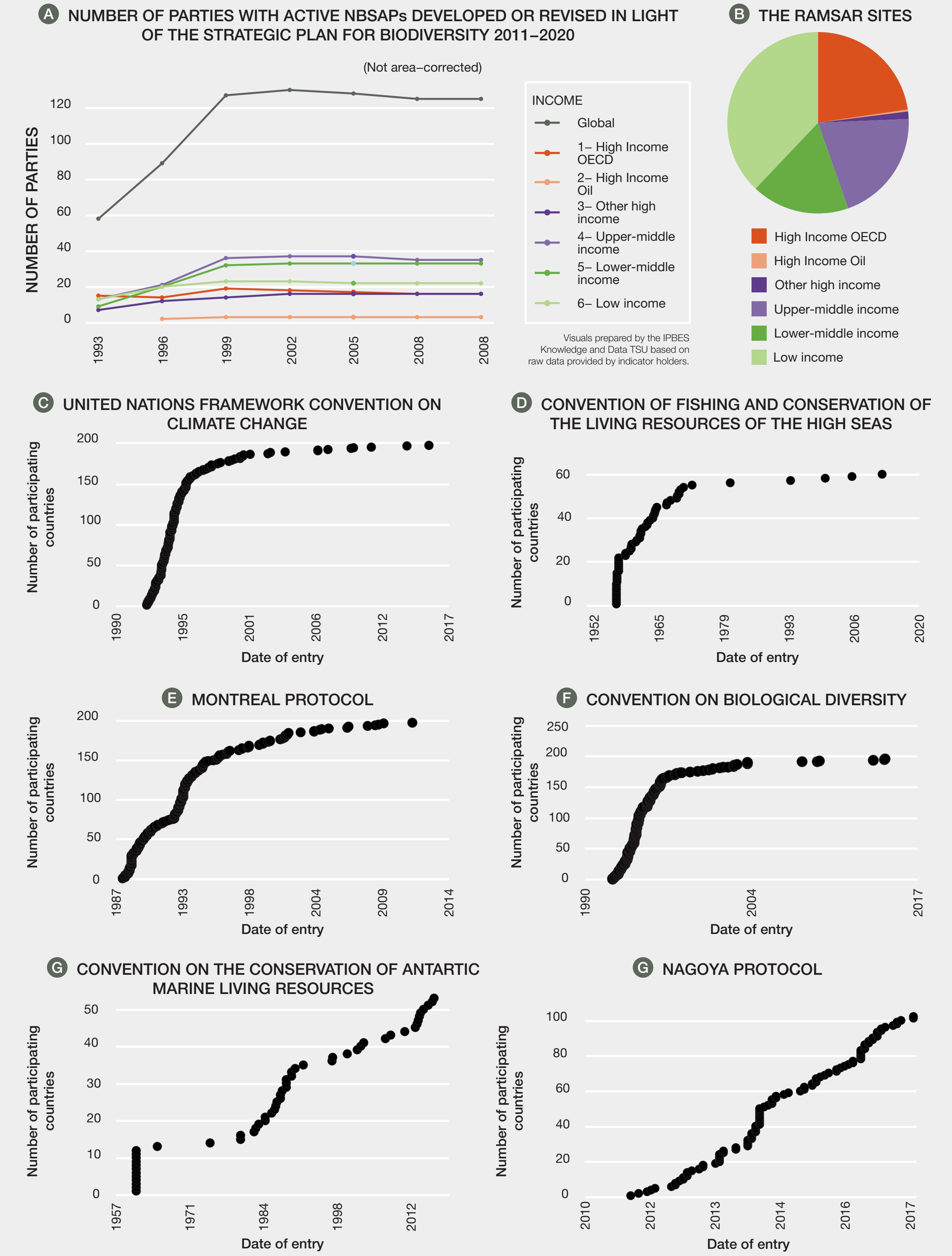


Figure 2 1 11 **Temporal trends in number of parties joining global agreements:**

A Parties with active National Biodiversity Strategies and Action Plans (NBSAPs) as per the Strategic Plan for Biodiversity 2011-2020; B Ramsar sites area per category of countries; and the number of countries in C the United Nations Framework Convention on Climate Change (1990~2017), D the Convention of Fishing and Conservation of the Living Resources of the High Seas (1952~2034), E the Montreal Protocol (1987~2014), F the Convention on Biological Diversity (1990~2017), G the Conservation of Antarctic Marine Living Resources (1957~2012), and H the Nagoya Protocol (2009~2017).

Average values per country using World Bank income categories for Figures A and B: High Income OECD (a:21, b:) High Income Oil (a:3, b:), Other high income (a:16, b:), Upper-middle income (a:40, b:), Lower-middle income (a:34, b:), Low income (a:27, b:) and Total (a:141, b:). Source: (Australian Government - Department of the Environment and Energy, 2017; CBD, 2018a, 2018b; UN, 1966; UN Secretariat to the Antarctic Treaty, 2018).

Fisheries Management Organizations (RFMOs) were established to manage highly migratory stocks, such as different tuna species. Around this time, global fishing effort shifted to the Southern Hemisphere, as key fish stocks in the Northern Hemisphere stocks were depleted. Latin American countries then began to claim jurisdiction over the 200 miles extending from their coastlines. Expansion of global fishing fleets prompted the establishment of national sovereignty over coastal waters via the United Nations Conference on the Law of the Sea convention (meetings 1958 to 1982). Exclusive economic zones (EEZs) were established, giving jurisdiction over 200 nautical miles from national coasts. This allowed countries to manage fish stocks in their national waters using licensing systems to restrict or more generally manage both national and foreign fishing vessels in those waters.

Other key international agreements within this sector include the UN Convention on Fishing and Conservation of Living Resources of the High Seas, as well as the FAO Code of Conduct for Responsible Fisheries that promotes a 'precautionary approach'. In addition, the Convention on the Conservation of Antarctic Marine Living Resources established an MPA and the closures of bottom-trawling fisheries to protect resources located outside of national jurisdictions (Caddy & Cochrane, 2001; Wilen *et al.*, 2012; Wright *et al.*, 2015).

International cooperation on transboundary environmental degradation (water, air, CO_2) also has been studied (Barrett, 1999, 2001, 2013; Barrett & Stavins, 2003; Wood, 2011). Cooperation can be 'strategic', depending on beliefs about the decisions of others, creating an obvious setting for spillovers from one country's decisions. While getting cooperation can be daunting if goals are insufficient or too ambitious (Barrett *et al.*, 2006; Vale, 2016), participation tipping points can be reached if enough countries join then (Barrett & Dannenberg, 2015; Green, 2015).

Alternatively, agreements among smaller sets of countries with common interest are highlighted. Though not global solutions, they are superior to countries acting alone (Finus *et al.*, 2009; Tavoni, 2013). Multiple such small agreements, each acceptable within like groups, could constitute complementary elements in global political frameworks for environmental governance (Falkner *et al.*, 2010; Hale & Roger, 2014). Technical innovations matter greatly. Barrett *et al.* (2006) shows that technologies with increasing returns can succeed where coordination by countries is possible: if the treaty enters into force only after a specific number of countries has signed on, then no country loses and each country could gain from signing on after that number.

Focusing on biodiversity in particular, CITES is an example of a form of global governance that is evolving in implementation via interaction with its member states, in light of species scarcity. CITES is an agreement between governments to ensure that international trade in specimens of wild animals and plants does not threaten their survival. Its implementation responds to changes in nature to ensure that biodiversity is not compromised. UN member states signed CITES, then established a mechanism to implement the agenda. For example, the government of India signed and ratified in 1976, then established a CITES Management Authority, coordinated by a Director in Wildlife Preservation, alongside authorities including the Wildlife Crime Control Bureau.

Efforts to enforce CITES' provisions have affected how species-based trade and illegal activities are regulated, with provisions to reform national-level environmental legislation in conjunction with the CITES Secretariat (administered by UNEP in Geneva). For instance, India amended its Wild Life (Protection) Act of 1972 to integrate CITES provisions, then took several initiatives to build capacity for implementation, such as establishing a self-sustaining multilateral mechanism (including China, Germany, India, Kenya, South Africa, Thailand, Uganda and United States) for funding a program to Monitor the Illegal Killing of Elephants (MIKE) in Asia. Along these lines, Nigeria put in place guidelines for wood-product vendors to require letters of support and CITES permits. That may indicate a shift to sustainable harvesting, updated per species' threats. Yet impacts remain unclear for these iterations between countries and international instruments.

2.1.11 INDIRECT-TO-DIRECT DRIVERS: ACTIONS THAT DIRECTLY AFFECT NATURE

Given the demands for a good quality of life, and characteristics of society including governance, individuals and societies undertake actions with intentional and unintentional impacts on nature. Each action can be carried out in different ways, with different impacts on nature and on actors. Major trends for actions and impacts are shown in **Figure 2.1.12** for groups of countries with different development levels (https://www.un.org/en/development/desa/policy/wesp/wesp_current/2014wesp_country_classification.pdf), revealing the global trends (see Figure S17). Actions (economic sectors) and their direct consequences on ecosystems are discussed below.

2.1.11.1 Fisheries, Aquaculture and Mariculture

Fisheries, aquaculture and mariculture play an increasing role in food security, livelihoods, and the global economy, yet fish stocks are being depleted. Fish provide ~20% of all animal protein globally (FAO, 2009b), and almost 60 million people were engaged in fisheries and aquaculture in 2012, most in Asia (84%) and Africa (>10%) (FAO, 2014). Value added in fisheries in 2011 was estimated to be over US$24 billion, i.e., 1.26% of the GDP of all the African countries.

Industrial fishing's footprint is 4 times that of agriculture, covering at least 55% of oceans' areas. Data from a new digital platform (Global Fishing Watch, 2018; Kroodsma *et al.*, 2018; McCauley *et al.*, 2016) allows for remote monitoring of vessels in the sea, providing new insights **(Figure 2.1.13)**. They permit monitoring of the 2012–16 activities of more than 70,000 industrial fishing vessels. As much as 85% of the fishing in remote parts of the oceans was by only five countries (China, Spain, Taiwan, Japan and South Korea). Global fishing hot spots include the northeast Atlantic (Europe) and northwest Pacific (China, Japan, and Russia), plus upwellings off South America and West Africa **(Figure 2.1.13)**. Lowest efforts were in the Southern Ocean, the northeast Pacific and the central Atlantic, and in the exclusive economic zones (EEZs) of many island states **(Figure 2.1.13)**.

Smal-scale or non-industrial fisheries (SSF) comprise a large share of global fisheries. SSFs account for over 90% of commercial fishers (over 100 million people), and nearly half (46%) of the global fish catch (Basurto *et al.*, 2017; Béné, 2008; World Bank, 2012). SSF practices entail less bycatch, less destructive gear, and less fuel consumption (Pauly, 2008), more sustainable than industrial fisheries, though with considerable ecological impacts (Alfaro-Shigueto *et al.*, 2010; McClanahan *et al.*, 2009). Yet, SSF statistics are often unreported (FAO, 2016b; Salas *et al.*, 2007). FAO efforts to elevate the profile of SSFs (FAO, 2014) have been improving the reliability and the quality of SSF data (FAO, 2016b).

While three-quarters of major marine fish stocks are fully or over-exploited or depleted —3% underexploited, 20% moderately, 52% fully, 17% overexploited, 7% depleted, 1% recovering from depletion (FAO, 2005, 2016b), efforts are being undertaken to shift trends and increase sustainability. The global fishery community is incrementally adopting sustainable development principles since 1992, including under the umbrella of mainstreaming biodiversity (Friedman *et al.*, 2018). Cross-sectoral cooperation has also been particularly critical to address disagreements, with approaches increasingly including biodiversity considerations. Conservation increasingly adopts more socially inclusive approaches. Efforts on sustainability relate to the Maximum Sustainable Yield (MSY; UN, 2017), which sets harvesting standards. Also, ecologically sound farming systems include aquaculture and integrated farming systems. For instance, in December 2016, 296 fisheries in 35 countries were certified as sustainable by the Marine Stewardship Council Fisheries Standards aiming for healthy ecosystems and long-term sustainability of stocks. Marine spatial planning to reduce conflicts between large- and small-scale fisheries as well as other sectors is increasing in many parts of the world (Douvere & Ehler, 2006). Such planning encompasses ecosystem-based management (FAO, 2003; see McLeod & Leslie, 2009), marine protected areas (FAO, 2011a), and an adaptative management perspective based on participation of the diverse stakeholders (Ehler & Douvere, 2009; Levin *et al.*, 2018).

In contrast, knowledge of inland fisheries is limited, despite societal and ecological significance. Inland fisheries are in lakes, reservoirs, rivers, floodplains, wetlands, lagoons and estuaries. Their economic and food security contributions can be invisible (Lynch *et al.*, 2016, 2017; Youn *et al.*, 2014), with inaccurate or unavailable data (Bartley *et al.*, 2015). Currently, global estimates (FAO, 2016b) suggest a production of about 11.9 million metric tons, over 12% of fisheries production. Over the past decade, the outputs from inland fisheries rose by over 30% despite threats from dam construction, water withdrawals, and pollution. For instance, migratory Caspian sturgeons lost 90% of their habitats (Barannik *et al.*, 2004).

Global fish production is concentrated in a few countries and firms. Overall, Asia accounted for 89% by volume and 79% by economic value in aquaculture (Bostock *et al.*, 2010). Thirteen large corporations from seven countries control a significant fraction (11–16%) of global marine catch (9–13 million tons) and control the largest stocks, with the highest economic values (19–40%), while operating through an extensive global network of subsidiaries (Österblom *et al.*, 2015).

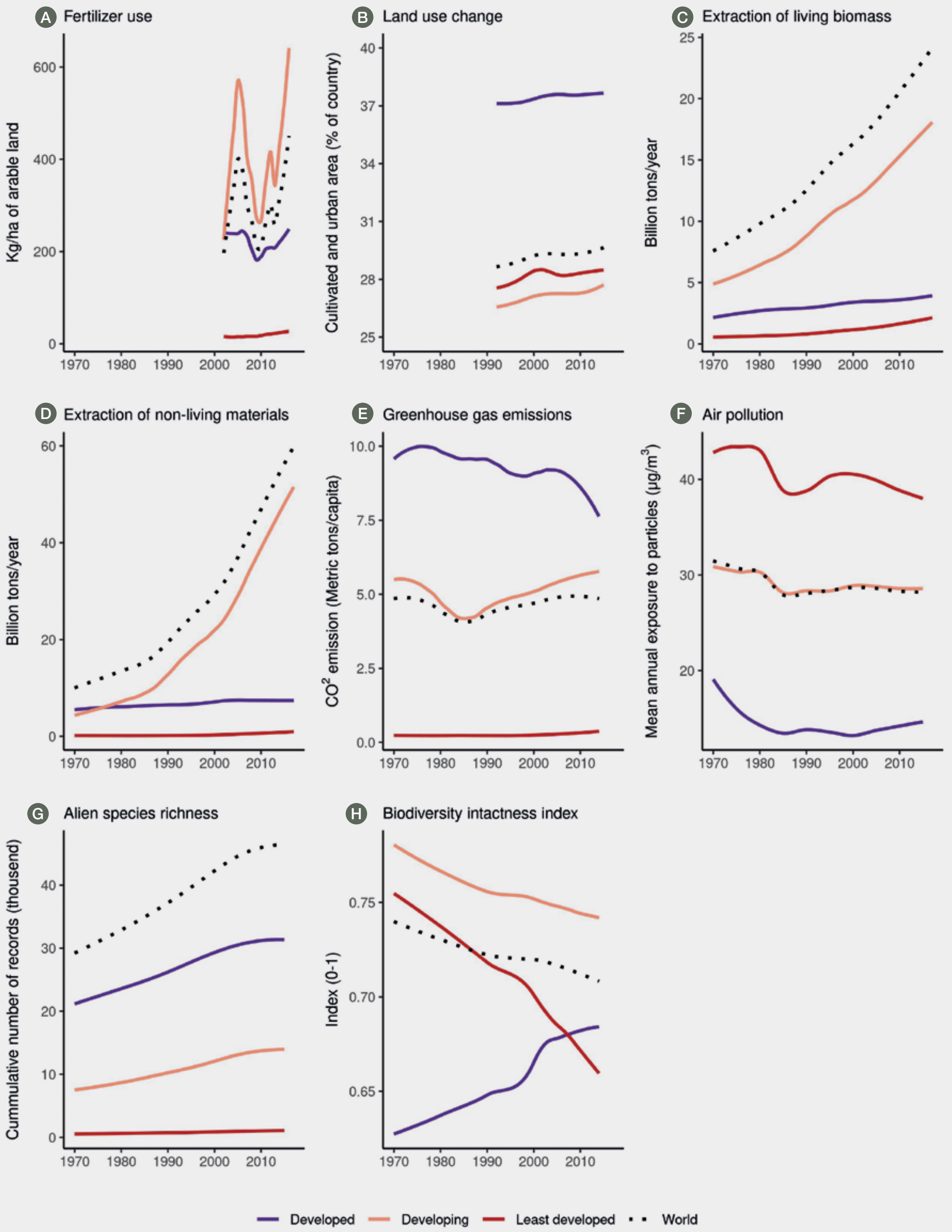


Figure 2 1 12 **Temporal trends for selected indicators of actions and direct drivers.**

Data shown are trends, per country, averaged (A, B, E, F, H) or totaled (C, D, G) by development categories: A **Fertilizer use:** Fertilizer consumption measures the quantity of plant nutrients (kg) used per unit of arable land per year; B **Fraction of cultivated and urban area:** Proportion of total area of country with cultivated and urban land cover, based on ESA CCI Global Land Cover v2.0.7; C **Extraction of living biomass:** Millions of tons per year extracted from agriculture, forestry, fishing, hunting and other types of living biomass; D **Extraction of nonliving materials:** Millions of tons per year extracted of fossil fuels, metal ores, and minerals for construction and industry; E **Per capita greenhouse gases emissions:**

metric tons of CO_2 emitted per year; E **Air Pollution:** mean annual exposure to particles larger than 2.5 micrometer of diameter in micrograms per cubic meter; G **Alien species:** Cumulative number of first records of alien species; H **Biodiversity intactness index:** relative change in abundance of native species as compared to a pristine system. Source: ESA (2017); FAO (2018b); Newbold *et al.* (2016); Ritchie & Roser (2018); Seebens *et al.* (2017); World Bank (2018c); WU (2017).

A

B

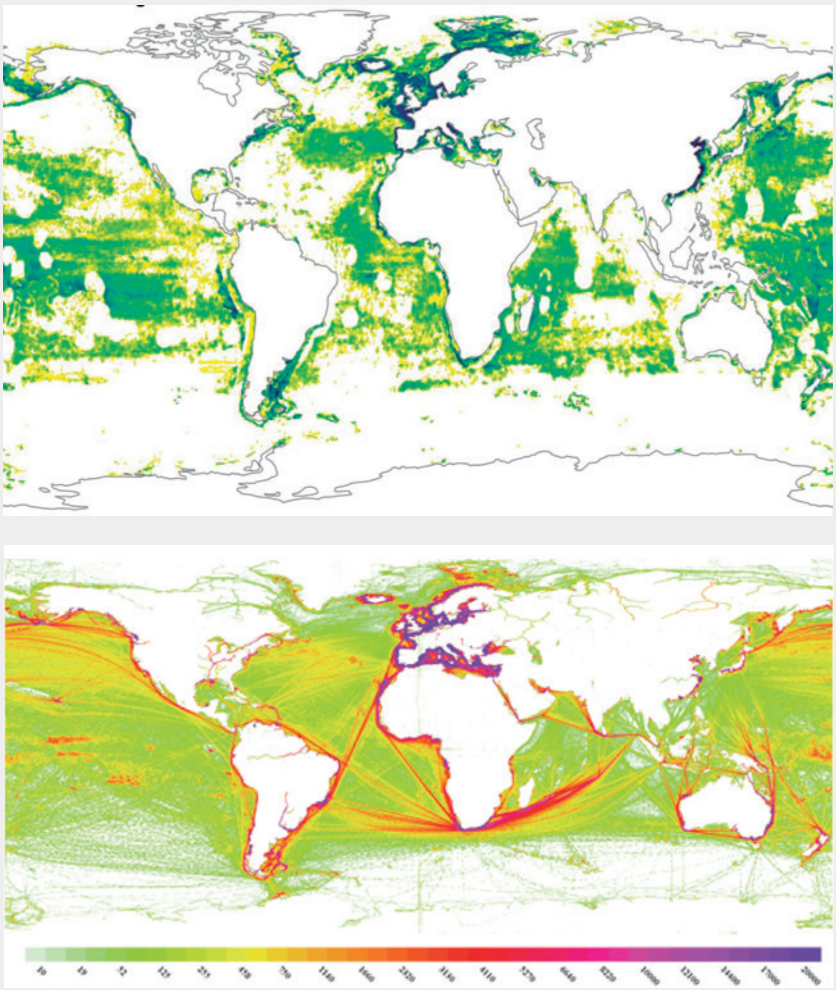


Figure 2 1 13 **Fishing and transportation impacts on the global oceans of all vessels detected with Automatic Identification Systems (AIS).**

A The spatial footprint of fishing. Effort (hours fished per square km (h km-2)) in 2016. B Global Network of Ship Movements (data 2012). Daily records for each 0.2° x 0.2° grid cell. Colored scale shows the number of messages recorded over the year in a cell. The boundaries, names and designations used do not imply any form of official endorsement or acceptance by the United Nations. Source: (Kroodsma *et al.*, 2018; UN, 2016d).

The contribution of aquaculture to global fish production is increasing, with an average annual expansion rate of 9.5% and 6.2% in 1990–2000 and 2000–2012, respectively (FAO, 2014). Yet its contribution to the total fish production has widely fluctuated, especially after 2000 (OECD, 2016). This expansion has incorporated an increasing list of species with different regional and economic importance values (FAO, 2014). The production of aquafeed has increased four times to 29.2 million tons by 2008 (UN, 2017) and it is contributing to national economies (US$6.4 billion in 2014), particularly within developing countries. Fishmeal and fish oil are produced mainly from harvesting stocks of small, fast reproducing fish (e.g., anchovies, small sardines and menhaden). Aquaculture is also emerging as an ecologically friendly alternative (Cottier-Cook *et al.*, 2016), although its growth is having mixed effects upon coastal and marine ecosystems (Figure S19). For instance, selective fish farming for high-performance breeds affects species diversity (Zhou *et al.*, 2010). Aquaculture also contributes to coastal habitat destruction via both wastes (nutrients, feces, antibiotics) disposal and introduction of invasive alien species and pathogens. Aquaculture also contributes to further depleting fish stocks, due to the large fish meal and fish oil requirements (Naylor *et al.*, 1998, 2000). These effects are species dependent. For instance, shrimp and salmon farming have net negative effects, while carp and mollusk farming have net positive effects on global fish supply and food security (Naylor *et al.*, 2000)**.**

2.1.11.2 Agriculture and grazing (crops, livestock, agroforestry)

The wide range of agricultural systems includes plant and animal-based systems, mixed farming, and newly emerging organic, precision, and peri-urban agricultural systems. Agroecosystems cover close to 40% of lands and continue to expand as there is a need to provide food, fuel and fiber for the 9–12 billion people expected by 2050 (Nyaga *et al.*, 2015). More than 175 species constitute the most frequently and extensively cultivated species, globally, with large variations in agricultural yield (Monfreda *et al.*, 2008). While agriculture's inputs and its outputs constitute the bulk of world trade, most food produced today is consumed domestically.

In 2000 there were 15.0 million km^2 of cropland (12% of the Earth's ice-free land surface) and 28.0 million km^2 of pasture (22%) (Ramankutty *et al.*, 2008). Impacts from agriculture are huge (HLPE, 2013; Pretty *et al.*, 2006; SDSN, 2013), e.g., 70–90% of withdrawals from rivers, lakes, and aquifers (Foley *et al.*, 2005) and 25% of global greenhouse gas (GHG) emissions from land clearing, crop production, and fertilization (Burney *et al.*, 2010). During 1980–2000, most new agricultural lands in the tropics came at the expense of intact or disturbed forests (Gibbs *et al.*, 2010). In Africa, agricultural expansion is farming for subsistence (small plots for sorghum, maize, millet) but sugarcane and soybeans are responsible for most agricultural expansion in South America. Rice, wheat, millet, and sorghum dominate South Asia, consistently over time, though tree plantations increased from ~11 to ~17 million hectares between 1980 and 2000, with oil palm plantations responsible for over 80% of this expansion, particularly since the 1990s (Gibbs *et al.*, 2010; Ramankutty *et al.*, 2008).

Agricultural intensification has also increased, with mixed social and ecological outcomes. For instance, water withdrawals and pesticide use have doubled, fertilizer use has tripled, chicken density has increased 10-fold, and cattle density has risen by 20% (Figure S20). Between 1985 and 2005 crop production rose 47% as yields rose 28%, while global crop and pasture lands rose 3%, largely in the tropics (Foley *et al.*, 2011; Poore & Nemecek, 2018). Extensive grazing occurs in 91% of lands, with intensive rising to 9%, largely for livestock production (IPBES, 2018a). An analysis of 60 cases found that agricultural intensification rarely leads to win–win social-ecological outcomes, often increasing food or provisioning services with mixed outcomes for regulating services, that support long-term productivity, and overall well-being (Rasmussen *et al.*, 2018).

Livestock production uses a third of crop production for feed and three quarters of land in total, with consequences for nature as animal-based foods, and especially beef, require more water and energy than plant-based foods (Ranganathan *et al.*, 2016). This all translates into greenhouse gas emissions as well (FAO, 2008). Substantial variation exists in conversion efficiency (i.e., animal products divided by feed to produce them), from 8–10% in Europe to only 1–2% in sub-Saharan Africa, Latin America and South Asia (Krausmann *et al.*, 2008).

Diverse agricultural systems exist, though, with combinations of short-lived and perennial crops together with timber and non-timber products developed over centuries in rural areas, including by IPLCs. Varied agro-silvo-pastoral systems allow maintenance of biodiversity, lower nature's degradation and provide a wide range of material, regulating and non-material contributions (Altieri *et al.*, 2012; Balvanera *et al.*, 2014; González-Esquivel *et al.*, 2015; Kanter *et al.*, 2018; Moreno-Calles *et al.*, 2015). Yet, the associated local and indigenous ethnoecological knowledge is being eroded by migration, urbanization, affected by extension programs, and by agricultural policies oriented to expand the areas under intensive pesticide-based monocultures in support of the international trade of agricultural commodities. For instance, a 70% decline in the cultivation of native plant varieties was observed in the Asia and the Pacific region, with reductions in genetic resources (IPBES, 2018b).

Still, small landholders play crucial roles. It is estimated that small-scale (< 2ha) farms generate ~30% of crops and food supply, using 24% of land, and with high agrobiodiversity (Ricciardi *et al.*, 2018). They also play a key role in maintaining the genetic diversity of managed species (IPBES, 2018b). In Mexico, for example, small-holders cultivating rainfed maize reach yields equal to 3 t/ha, and can feed more than half of the country's population while having a large genetic diversity (Bellon *et al.*, 2018).

As pristine areas fall, the design and management of sustainable agroecosystems (Altieri, 1995) has been applied in agroforestry, sustainable intense agriculture, and integrated pest management (Barrios *et al.*, 2018) with gains for biodiversity and ecosystem services (Bawa, 2004; Du Toit *et al.*, 2004; IAASTD, 2009; Nyaga *et al.*, 2015; Pimentel *et al.*, 1992; Schroth *et al.*, 2004; Tscharntke *et al.*, 2005; Vandermeer & Perfecto, 1995). Zomer *et al.* (2016) find for 2010 that over 43% of agricultural lands had at least 10% tree cover (FAO forest definition). This can connect forests, as is the case within the Mesoamerican Biological Corridor (MBC) launched in 1990 to link forests in northern Colombia with those of southern Mexico.

Organic agriculture has also developed rapidly in more recent decades, including in larger-scale systems, with a focus on utilizing lower off-farm inputs and, where possible, cultural, biological and mechanical pest management. By 2006, such practices covered over 31 million ha in 120 countries (Alexandros *et al.*, 2012). With variable outcomes, they may improve biodiversity, soil and water quality and nutritional value, although not always providing higher yields and lower consumer prices when compared to large-scale monocropping (Seufert & Ramankutty, 2017).

2.1.11.3 Forestry (logging for wood & biofuels)

Between 1990 and 2015, global forest area fell from 4.28 billion to 3.99 billion ha, while the area of planted forests rose from 167.5 to 277.9 million ha (Payn *et al.*, 2015). Forests currently cover one-third of terrestrial area (FAO, 2012a), and a large fraction of people depend at least in part on forests (FAO, 2012a). A challenge has been to manage forests to sustain livelihoods and yet maintain regenerative capacity to ensure long-run survival of forests (MacDicken *et al.*, 2015).

Global harvests of roundwood in 2017 were estimated to be 3.9 billion m^3 of which 1.9 billion were industrial and 1.9 billion were fuelwood (~50% respectively) (FAO, 2018c). Harvests of industrial roundwood are falling in high income OECD countries but increasing in lower-middle and upper-middle income countries (Figure S22). Asia has the highest proportion of agricultural land (52%) and the lowest of forest (19%). Temperate areas within East Asia, Europe, North America, and Southern and Southeast Asia show the largest increases in planted forests. Native species are found within 80% of the planted forests, while introduced species dominate in South America, Oceania and Eastern and Southern Africa as a result of industrial forestry there.

Much forest biomass generates energy, as solid, liquid and gaseous fuels, accounting for 14% of the global energy mix in 2014 (IEA, 2017), while generating greenhouse gas emissions. Between 1960 and 2014, bioenergy use rose 2.7-fold, most in Africa (4.1-fold), yet the share of bioenergy in energy supply declined (15% to 10%) over the same period (De Stercke, 2014). Global use of fuelwood peaked in the mid-1970s and has been falling since the 1980s. Over a quarter of global fuelwood harvested in 2009 was deemed unsustainable, with geographical variations. Over 250 million rural people live in fuelwood-scarcity "hotspots", mostly in South Asia and East Africa (Masera *et al.*, 2015). Of all wood in fuel, about 17% is converted to charcoal, of which production rose over 3-fold during 1961–2015 (FAO, 2016a) given the population growth, poverty, urbanization and prices of alternatives (FAO, 2017a).

Over decades, and centuries, the maintenance of forest cover and biodiversity has been possible, in cases at least, alongside the harvesting of timber and non-timber forest products. Experiences from implementing sustainable forestry in past decades shows that it can achieve higher levels of success where attention is given to planning, establishing permits, and legal rights (MacDicken *et al.*, 2015). As discussed above, forest certification standards for sustainable harvest have been developed by several organizations, including the Forest Stewardship Council (FSC, 2018) and the Programme for the Endorsement of Forest Certification (PEFC, 2018). For tropical forests, such certifications have, in cases, provided varied environmental and social benefits for local communities, with lower short-term profits (Burivalova *et al.*, 2017).

Sustainable community forestry is found in Latin America (Mexico, Central America, Colombia and Peru), Canada and the US (Gilmour, 2016; Merino & Cendejas, 2017; Nagendra, 2007), while sustainable family forestry occurs in Northern and Central Europe (Finland and Austria). Often, community forest is managed within agroforestry systems such as for shade coffee and cacao. For instance, within the lands of IPLCs in Mexico and Central America, there is evidence that community forestry is as efficient as protected areas in preserving forests and conserving biodiversity (including both bird and mammal species) and reducing rates of greenhouse gas emissions (Bray & Merino-Pérez, 2004; Duran-Medina *et al.*, 2005; Merino & Cendejas, 2017; Merino-Pérez, 2004). However, economic and environmental benefits of community management are still understudied and, in the case of tropical forests, its social impacts could be either positive or negative (Burivalova *et al.*, 2017).

2.1.11.4 Harvesting (wild plants and animals from seascapes and landscapes)

Harvesting and use of non-timber forest products (NTFPs) is a core component of livelihoods for forest-dependent communities around the world. About 350 million people in or adjacent to forests depend on NTFPs for subsistence and income (World Bank, 2004). NTFPs include any biological resources found in forests other than timber (e.g., seeds, oils, foliage, game animals, medicinal plants, spices, bark, mushrooms, fuelwood). Poor rural populations heavily depend on medicinal plants when healthcare is limited, with Africa being most dependent (IPBES, 2018b).

Data are patchy, as consumption is often local, outside markets, and not within national statistics. A meta-analysis of 51 studies in 17 countries found that NTFPs represented, on average, 22% of total income for sampled populations. They also play key roles as equalizers of local income distributions (Vedeld *et al.*, 2007) because the poor rely more on them. A study (Belcher *et al.*, 2005), of close to 100 cases across Africa, Asia and Latin America supports that the households with lower incomes relied more on NTFPs for their livelihoods – such that degradation and overexploitation impact the rural poor more (Belcher *et al.*, 2007; Shackleton & Shackleton, 2004), especially the old and the young.

Some NTFPs have large markets. For instance, maple syrup earned ~US$350 million in 2015, up 18% from 2011. Canada produced 82% of it, followed by the US (7.6%) and Germany (2.3%) (Barlow *et al.*, 2015). Rattan from humid and sub-humid forests in Indonesia (80%) earned over US$70m (62,000 tons) in 2008, down 70% from 2000 (Hirschberger, 2011). Empirical evidence is biased towards such traded NTFPs, which are a small fraction (Belcher *et al.*, 2005). While commercialization may maintain and even improve livelihoods, market chains with many intermediaries can lower local economic returns and increase overexploitation of the products (Buda Arango *et al.*, 2014; Marshall *et al.*, 2006).

Bushmeat is an important source of protein and provides food security and livelihoods for many forest-dependent rural and urban populations in low- and lower-middle income countries. In the tropics, at least 6 million tons of large to medium size mammals, birds and reptiles are harvested every year (Nasi *et al.*, 2011), with 1 to 5 million tons within the Congo Basin alone (Fa *et al.*, 2003; Wilkie & Carpenter, 1999). About a third is commercialized and reported in national statistics (Karp *et al.*, 2015; Nasi *et al.*, 2011). Many species can survive high offtake but for slow-breeding species even low offtake can be devastating (Van Vliet *et al.*, 2010, 2007). Some literature suggests that the rare species are seldom targeted and are a small share of offtake (Abernethy & Ndong Obiang, 2010; Nasi *et al.*, 2011; Van Vliet *et al.*, 2010), yet a large number of primate species are threatened.

In high and middle income countries, hunting, and trophy hunting in particular, now are mostly recreational, aimed at large game species (bears, wolves, lynx, red deer, wild boar) and at birds (ducks, geese, waders, doves, passerines). Around 6 million wild ungulates are harvested every year, with a mixed set of motivations (Bauer & Giles, 2002). Yet hunters have declined in many parts of Europe and the US. Game fishing targets larger members of many species, which tend to be the most fecund, yielding disproportionate impacts on biodiversity. A large number of species (85) targeted by the International Game Fish association are considered 'threatened' by IUCN. In contrast, most Arctic hunting and fishing is for local consumption – often regulated separately (CAFF, 2013) – with nutritional and cultural significance, especially for Indigenous Peoples.

2.1.11.5 Mining (minerals, metals, oils, fossil fuels)

Mining activities directly and indirectly affect the livelihoods of most people around the world, via contributions to the production and use of minerals, metals, oils and fossil fuels. Hundreds of mineral commodities have uses in energy, construction, manufacture, and industrial processes. Mining contributes a large fraction of the world's GDP, particularly among emerging economies, with over 60% of GDP for 81 countries in 2014, and more than 17,000 large-scale sites in 171 countries (Matos *et al.*, 2015). Oil, gas, coal and minerals (e.g., bauxite, copper, gold, iron ore, lead, nickel, phosphate rock, silver, tin and zinc) are close to a quarter of natural capital globally, and close to 7% of total wealth (World Bank, 2006). Thus, this is an extremely important economic sector.

Yet, it features imperfections in rights, markets and legal structures. Valuable resources have had destructive consequences as well, such as in Africa's 'diamond wars' (Gylfason, 2009), although systematic quantitative global data on these issues largely are missing. As global gold demand increased after the international financial crisis, within the South American moist forest ecoregions more than 90% of the deforestation linked with gold mining occurred within four major hotspots: Guianan (41%), Southwest Amazon (28%); Tapajós–Xingú watersheds (11%); and Magdalena–Urabá along with Magdalena valley montane forest (9%) (Alvarez-Berríos & Aide, 2015). Some of the more active zones for all this deforestation associated with gold mining deforestation occurred in or within 10 kilometers of protected areas (Alvarez-Berríos & Aide, 2015).

Mineral deposits of *Al, Fe, Cu, Au*, and *Ag* are concentrated in the Andes, Rocky Mountains, North-East America, Australia, South-eastern and Western Africa, Northern and Eastern Europe, and in Eastern and South-Pacific Asia. Globally, bauxite and silver mines are within zones with intermediate to high biodiversity (Murguía *et al.*, 2016). Further, as the ice melts with climate change, new areas are opening up to mining within the Arctic and the Antarctic regions, including with important petroleum reserves in the Arctic (AMAP, 2018).

Surface mining is a driver of land-cover change, pollution of surface and ground water, and air quality degradation, constituting a health hazard in many regions. Although it occupies under 1% of land area, it has negative effects upon vast areas (Schueler *et al.*, 2011; Sonter *et al.*, 2014), locally for biodiversity perhaps more than agricultural expansion (Deikumah *et al.*, 2014). Severe landscape transformations include not only deforestation but also the opening of pits, vast amounts of waste, large quantities used of freshwater, and chemical and physical pollutants released into air, land and water (Palmer *et al.*, 2010). Coal and gold mining (Epstein *et al.*, 2011; Palmer *et al.*, 2010) can severely modify a landscape, including via extensive destruction of forest and the corresponding loss of habitats (Asner *et al.*, 2013; Swenson *et al.*, 2011; Wickham *et al.*, 2007).

Subsequent processing also released carbon dioxide, sulfur dioxide, methane, particulate matter, mercury and other heavy metals, generating acid rain and raising the bioavailability of mercury and other heavy metals (Epstein *et al.*, 2011; Palmer *et al.*, 2010). In the main gold production region of Colombia, gold mining is responsible for the highest reported concentration of mercury in the air (a thousand times above the WHO's allowable level) (Cordy *et al.*, 2011), putting ~150,000 people at high risk of mercury poisoning (Spiegel, 2012). Artisanal and small-scale gold mining is the leading source of anthropogenic mercury emissions globally (UNEP, 2013). Mining also occurs in oceans, in over 50 countries. While seabed mining is a currently relatively small, the growing demand for minerals has led to 18 contracts granted in the last 4 years by the International Seabed Authority (ISA), for ~1 million km^2 in the Pacific, Atlantic, and Indian Oceans beyond any national jurisdiction (Wedding *et al.*, 2015).

While large companies produce most of the minerals traded internationally, small-scale mining is an important economic activity, particularly in the developing world. Many poor rural people see it as a best livelihood option (Spiegel, 2012), yet they may not capture much economic surplus in the value chain (Hilson, 2003; Hinton, 2005). Whole countries rich in minerals have had limited long-term impacts on their economies from mining. Latin America has large deposits of copper, iron, gold and silver. Chile, Bolivia and Peru are the major mining countries of South America. Africa is estimated to have 40% of the world's gold, 60% of cobalt, and 90% of platinum. Yet, booming mining sectors in mineral-rich countries may not have large gains in local communities, especially when also taking into account environment and health impacts (Gordon & Webber, 2008). Many countries have been unable to use mining wealth to greatly boost their economies (Auty, 2006; Sachs & Warner, 1995). Furthering the potential for local net costs, the sector also has been linked to social and environmental conflicts, and illegal activities, with a few large multinational companies controlling large networks of exploration sites with the largest human rights violations (Inter-American Court of Human Rights and Bebbington & Bury, 2013; see sections 2.1.6.3.2 and 2.1.9.1).

2.1.11.6 Infrastructure (dams, cities, roads)

While the development of infrastructure has negative direct consequences on the environment, it has both negative and positive indirect effects (see also sections 2.1.5.3, 2.1.6.2, 2.1.9.1.2, 2.1.11.1). Rivers have been modified for thousands of years to regulate floods and to ensure water supply for irrigation, industries and settlements, recreation, navigation and hydropower generation. Over past decades, the numbers of dams and reservoirs, and their overall storing capacities, have greatly increased. Currently, about 50,000 large dams (higher than 15 m), and an estimated 16.7 million reservoirs (larger than 0.01 ha) hold approximately 8,070 km^3 of water (Lehner *et al.*, 2011). Close to 8% of the world's rivers are affected by cumulative upstream reservoir capacities exceeding 2% of the annual flow. Smaller reservoirs (> 0.5 km^3) account for a small fraction of the water stored, yet substantially affect rivers, increasing their spatial extent (Lehner *et al.*, 2011). These changes have decreased the global annual sediment flux to the coastal zones by 3.7 billion tons, leading to river sediment starvation and thus coastal erosion in delta regions and estuaries with negative consequences upon habitats, while increasing coastal and estuarine turbidity, negatively affecting biological systems. These estuaries and deltas are estimated to concentrate some of the largest population density in the world, including a large share of coastal mega-cities (UN, 2017).

Urbanization has multiple and complex linkages to the environment (Bai *et al.*, 2017; Grimm *et al.*, 2008). Currently, urban areas account less than 3% of the total land area (Grimm *et al.*, 2008; McGranahan *et al.*, 2005), although urban expansion is faster than urban population growth (UN, 2014), often driven by positive feedbacks between urbanization and economic growth (Bai *et al.*, 2012). From 1970 to 2000, urban land use expanded by 58,000 km^2 (Bai *et al.*, 2012; Seto *et al.*, 2011). The expansion of cities is linked to infrastructure to supply demands of urban living (e.g., transportation of people, goods, energy, water), with effects in and beyond the boundaries of urban areas. Growing urban populations create more impervious surfaces, which reduce water infiltration, affecting regional climates and hydrology (Chen *et al.*, 2010a; Tayanc & Toros, 1997; Žganec, 2012). Infrastructure development projects designed to address the supply of natural resources may also displace people, take agricultural land out of production, and alter ecosystems (Liu *et al.*, 2016c; Vitousek *et al.*, 1997b; Zhang, 2009). Yet, urban infrastructure attracts people from rural areas, potentially lessening the land uses in fragile and/or low productivity ecosystems, stimulating ecosystem recovery and improving biodiversity conservation (Aide & Grau, 2004; Grau & Aide, 2007; Grau *et al.*, 2003).

Urbanization is also a major cause of losses of lakes and wetlands in multiple countries (Davis & Froend, 1999; Prasad *et al.*, 2002; Wang *et al.*, 2008). Production and consumption in cities can exacerbate air and water pollution – with negative health consequences (Guo *et al.*, 2013; Liu *et al.*, 2016b; McMichael, 2000; Zhu *et al.*, 2012). Urban land expansion also reduces habitats, particularly in biodiversity hotspots (Elmqvist *et al.*, 2013; Seto *et al.*, 2012). Urbanization and urban activities shift spatial and temporal patterns of rainfall (Shi *et al.*, 2017), while physical structures influence regional temperatures through heat islands (Giridharan *et al.*, 2004; Sobstyl *et al.*, 2018). On the other hand, cities can also be champions of environmental stewardship, for instance by building flood-resilient cities and reducing varied emissions of greenhouse gases (Bai *et al.*, 2018; Solecki *et al.*, 2018). Biodiversity friendly cities are also now found (Botzat *et al.*, 2016).

Roads and transportation infrastructure have been associated with both increased pressures upon forests and habitats or, in contexts, relocation of pressures away from nature (Benítez-López *et al.*, 2010). New roads certainly have led to losses of forest (Boakes *et al.*, 2010; Laurance *et al.*, 2015) but with highly varied impacts depending on their contexts – from large losses to no net effects, across tropical forests in Latin America, to even some positive effects in more highly populated and developed areas, such as within India. The indirect effects of transportation investments through transport costs, and related responses, can be much bigger than the direct effects of projects (Edwards *et al.*, 2014; Weng *et al.*, 2013).

Increasing human encroachment, land reclamation, and coastal development have big impacts on coastal environments (UN, 2017) including on nature, e.g., mangroves that help with resilience. To meet growing land demand for housing and recreation, industry, commerce, and agriculture, large-scale land reclamation projects are increasing along coasts, although coastal protection is also increasing. Large-scale dredging has occurred in several countries in Asia and the Middle East, beyond the near-shore environments, for creation of airports, tourism facilities and islands. Land reclamation is linked to the degradation of wetlands, seagrass beds and decreased coastal water quality, with negative impacts on regional groundwater regimes discharges to the coasts.

Challenges posed by the growth of infrastructure vary by country (Bai *et al.*, 2017; McGranahan *et al.*, 2005), typically with more and better infrastructure as income rises (World Bank, 1994). High income countries have built more energy and telecommunications connections, as well as more extensive transport networks in locations with a higher density of population and industry. In contrast, while infrastructure has expanded tremendously in many rapidly growing cities and peri-urban settlement in Africa and South and East Asia, it still lags the growth of population and service demands – leading to local environmental degradation – while the inadequate design and maintenance of that new infrastructure lead to its severe deterioration and significantly reduced lifespans. Urban growth within the less-developed countries also brings complex challenges, as for increasing the provision of basic services, such as clean water and sanitation (Cohen, 2004, 2006; Elmqvist *et al.*, 2004; Hardoy *et al.*, 2013; Seto *et al.*, 2013; UN, 2014; World Bank, 2015b; Young *et al.*, 2009), although such challenges have also offered opportunities for locally developed solutions (Nagendra *et al.*, 2018).

2.1.11.7 Tourism (intensive and nature-based)

Tourism has dramatically grown in the last 20 years. Total international departures and arrivals tripled globally, with greater increases from high income and upper-middle income countries (Figure S23). Much is domestic, e.g.: 3,260 million versus 29 million international for China; and 1,600 million domestic tourism trips versus 70 million international for the US (UN, 2017).

Between 2009 and 2013, tourism's global carbon footprint rose from by 40%, from 3.9 to 4.5 $GtCO_2$-eq, accounting for ~8% of global greenhouse gas emissions (Lenzen *et al.*, 2018), with transport a big contributor. In 2010, tourism required 16,700 PJ of energy, 138 km^3 of fresh water, 62,000 km^2 of land, and 39.4 Mt of food (Gössling & Peeters, 2015). Yet impacts vary considerably: one-night accommodations require 3.7 - 3,700 MJ of energy depending on the luxury conditions of accommodations and transport. Largest increases have been observed for the most resource-demanding options for the growing global class of wealthy travelers (UN, 2017). Most of the footprint of tourism is exerted by high income countries. These rapid increases in demand are effectively outstripping decarbonizations of tourism-related technology (Lenzen *et al.*, 2018).

Demands for nature-based and eco-tourism also have risen. While the latter aims for consistency with conservation by operating at small spatial scales to minimize ecological and social impacts, the former often operates at larger spatial scales and promotes national development objectives (Brandon, 1996). Their effects are, thus, quite different. The number of visitors to 280 protected areas within 20 countries has been increasing over time in all countries, particularly in those with lower income levels – with the exception of the United States and Japan (Balmford *et al.*, 2009).

2.1.11.8 Relocations (of goods and people)

Transportation of goods and people has risen drastically in recent decades (see also 2.1.11.6). The number of air flights has doubled, globally, and tripled for high income OECD countries (Figure S23), while seaborne carriage of oil has doubled, general cargo has quadrupled, and the carriage of grain and minerals has nearly quintupled. Voyage lengths also have increased (UN, 2017).

Relocation of goods and people has direct, indirect and cumulative impacts on nature (Rodrigue *et al.*, 2016). Noise and toxic emissions – e.g., carbon monoxide – directly cause harm. Catastrophic events involving ships (such as collisions, fires, foundering, wrecks) produce serious direct impact on marine ecosystems (UN, 2017). Indirect effects include chronic impact along frequent trade routes **(Figure 2.1.13)**. Cumulative impacts include those upon the global climate, with 15% of the global CO_2 emissions associated with the transportation sector (Rodrigue *et al.*, 2016), and more than 3.5% of climate forcing attributed to air transportation (Lee *et al.*, 2010).

Introduction of invasive alien species is linked to transportation of goods and people. In both the 20th and 21st centuries, trade was one of the most important factors in the widespread distribution of invasive alien species in both aquatic and terrestrial ecosystems (Hulme, 2009; Seebens *et al.*, 2016) (Early 2006). Accidental introductions of invertebrates and algae had steep increases recently, as those species are difficult to regulate and are closely associated with increasing human activity such as trade, migration, and tourism (Hulme, 2009; Kowarik, 2011).

2.1.11.9 Restoration

With degradation currently impacting the well-being of at least 3.2 billion people, with losses of more than 10% of the annual global gross product (IPBES, 2018a), there is an urgent need for restoration to avoid biodiversity loss, mitigate climate change, and ensure continued global 'life support' (Aronson & Alexander, 2013; Navarro *et al.*, 2017). Sustainable land management practices, with restoration actions to avoid, reduce and reverse land degradation, have been shown to provide benefits that exceed their costs in many places, though their overall effectiveness is context-dependent (IPBES, 2018a). While financial costs are easy to quantify and can seem high, assessing restoration's short-, medium-, and long-term effects on nature's contributions is challenging. They are not all perceived and valued (IPBES, 2018a).

While recoveries due to restoration of ecosystems and landscape may not be complete (Benayas & Bullock, 2012; Jones *et al.*, 2018), they yield multiple direct and indirect benefits for nature and people: increased material benefits from nature; climate regulation; and also spiritual gains (Benayas & Bullock, 2012; Brancalion *et al.*, 2014; IPBES, 2018a). Restoring the structure and function of degraded ecosystems contributes to longer-term ecosystem resilience (Kaiser-Bunbury *et al.*, 2017; Suding, 2011) as well as to short-term mitigation and adaptations to climate change (Locatelli *et al.*, 2015). Restoration is an obvious complement to conservation for biodiversity (Possingham *et al.*, 2015) and ecosystem services. Ultimately, its goals depend on the extent and nature of degradation and local needs and decision processes. Recovery of the prior "intact" ecosystem may not be possible, or desirable, in some contexts (Hobbs *et al.*, 2014).

International conventions recognize the importance of restoration at national and global scales. Restoration is a key piece of Aichi Biodiversity Targets 14 and 15 established by the Convention on Biological Diversity (CBD). Ecosystem- and landscape-scale restorations are also approaches of the UN Convention to Combat Desertification, UN Convention on Climate Change, Ramsar Convention on wetlands, Convention on Migratory Species, and Sustainable Development Goals. The Bonn Challenge to restore 150 million hectares of forest 2020 was expanded by a United Nations' New York Declaration on Forests to restore 350 million ha by 2030 (IUCN, 2015). This is not just to plant trees but also to use regenerated forest sustainably, manage tree plantations, agroforestry and agricultural systems, and protect wildlife reserves with ecological corridors or river or lakeside planting to protect water (IPBES, 2018a). No similar global-scale challenge has yet been proposed for restoration of non-forest ecosystems.

Restoration is implemented by state agencies, local communities, non-government organizations, and the private sector. Approaches range from passive to active interventions, with distinct costs, limitations, and outcomes. Passive approaches that rely on natural recovery mechanisms have the highest rates and extent of recovery overall (Jones *et al.*, 2018), particularly for tropical forests (Crouzeilles *et al.*, 2017). Interventions can focus on specific habitats and ecosystems or at the scale of landscapes, encompassing mosaics of different land uses, ecosystems and land covers.

Yet large gaps remain between restoration targets and achievements, reflecting gaps in capacity, finance, policy, and enforcement (Stevens & Dixon, 2017). Restoration is legally mandated in some countries (e.g., Brazil, China), particularly after certain activities (e.g., mining or wetland drainage or as related to required protections for rivers and streams). Compensatory restoration, required in some countries, requires the party responsible for ecological damage to compensate the public for ecosystem services loss (Rohr *et al.*, 2018). In other cases, biodiversity offsets create a mechanism for off-site restoration to compensate for the biodiversity losses caused by development projects. For example, to offset vegetation losses due to industrial development of oil palm during 1973–2013, the industry would need to restore natural vegetation across 8.7% of Kalimantan (Budiharta *et al.*, 2018) in order to get to no net loss (rather than, e.g., any net gain).

Achieving restoration targets in international treaties and conventions will require avoiding more degradation and conversion of ecosystems, plus effective and long-lasting restoration practices at national scales (Chazdon *et al.*, 2017). With climate and biodiversity policies, this is a basis for progress on sustainable futures (Aronson & Alexander, 2013; Benayas & Bullock, 2012; Brancalion *et al.*, 2014; Budiharta *et al.*, 2018; Chazdon *et al.*, 2017; Crouzeilles *et al.*, 2017; De Groot *et al.*, 2013; Egoh *et al.*, 2014; Hobbs *et al.*, 2014; IUCN, 2015; Jones *et al.*, 2018; Kaiser-Bunbury *et al.*, 2017; Locatelli *et al.*, 2015; Navarro *et al.*, 2017; Possingham *et al.*, 2015; Rohr *et al.*, 2018; Stevens & Dixon, 2017; Suding, 2011; Suding *et al.*, 2015; Verdone & Seidl, 2017).

2.1.11.10 Illegal activities with direct impacts on nature

Illegal activities constitute major threats to nature and livelihoods. In maritime regions, they add to depletion of fish stocks. Coastal zones of developing countries are particularly susceptible to illegal, unreported or unregulated (IUU) fishing that peaked during the mid-1990s. In 2011, IUU fishing was estimated at 26m or 33% of global catch including fish and other marine fauna (UN, 2017) and 20–32% by weight of wild-caught seafood imported to the US (Pramod *et al.*, 2014). Locally, IUU fishing is highest off West Africa, estimated at ~40% of total catch, with 32% in the Southwest Atlantic and as much as 1.5 million tons/year in Indonesia (**Figure 2.1.14**; Agnew *et al.*, 2009). Note that 70% of vessels known to be linked to IUU fishing are flagged under tax-haven jurisdictions (Galaz *et al.*, 2018).

IUU fishing is lucrative, due to high-value species plus no taxes – as is permitted by weak governance (Fisheries and Oceans Canada, 2009). While efforts have improved oceans governance over the last decade, not all regions are overseen by regional fishery management organizations (RFMO) while not all RFMOs are effective in monitoring and controlling IUU fishing. The Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (PSMA), which came into force in June 2016, has grown to 54 parties (with all 28 EU members counting as just one). Endorsement by 170 states of the FAO Code of Conduct for Responsible Fisheries (CCRF) in 1995 has contributed to lowering IUU fishing. While this is voluntary, Australia, Malaysia, Namibia, Norway and South Africa, have incorporated provisions into national law. Recent improvements in vessel monitoring systems are available, for both larger- and small-scale fishing vessels, providing geo-referenced descriptions of fishing areas and at scales useful for policy (Global Fishing Watch, 2018; Kroodsma *et al.*, 2018; McCauley *et al.*, 2016).

Illegal forestry has important negative consequences on forests, aggregate economic wellbeing, and livelihoods of forest communities (Smith, 2004). Hoare (2015) has estimated that 80 million m^3 of timber was illegally produced in 2013 by the nine main producers in tropical countries. Overall illegal logging is estimated to be 10–15% of global timber production (Brack & Hayman, 2001; RIIA, 2017; SCA & WRI, 2004) though rates of up to 50% are reported for several countries (Guertin, 2003; Tacconi *et al.*, 2003). In 2013, Indonesia (50%), Brazil (25%) and Malaysia (10%) accounted for most of the illegal timber harvests worldwide, with large timber sectors (Hoare, 2015), while Ghana, Cameroon, DRC, Laos, Papua New Guinea and Republic of Congo are also large contributors, with much higher proportions of production being illegal (e.g., almost all DRC production) (Hoare, 2015). In 2013, illegal logging emitted over 190 million tons of CO_2, more than total emissions from Denmark, Norway and Sweden (Hoare, 2015). Economic impacts are largely revenue losses for states and, in some cases, private forest owners. These hurt livelihoods for forest-dependent people and displacements of people through corrupt land and forest acquisition practices (Pokorny *et al.*, 2016; Tacconi, 2007b). Illegal production of biofuel is large especially in Africa. Most wood pellets and fuelwood in Asia and the Pacific and Latin America are produced legally at medium to large scale, yet in Africa a significant share is associated with small-scale, poor, informal actors (Mohammed *et al.*, 2015). Fuelwood harvesting has the most effects on dry forest, grassland and savannas.

A number of factors have contributed to drive illegal logging, beyond the costs and the returns from sustainable forest management (Pokorny & Pacheco, 2014), including quite poor investment incentives for companies (Contreras-Hermosilla, 2001), poor governance ranging from weak enforcement capacity (Ehara *et al.*, 2018) and over-regulation to corruption including infringements of weak property rights (Alemagi & Kozak, 2010; Cerutti *et al.*, 2013; Contreras-Hermosilla, 2001; Pokorny, 2013; Pokorny *et al.*, 2016; Smith *et al.*, 2003; Tacconi, 2007a). Most of the reported illegal logging is industrial logging in developing countries, yet small scale (artisanal or chainsaw) and on-farm illegal logging has been reported as quite significant in some cases (Cerutti *et al.*, 2013; Hoare, 2015). Its growth is explained by two factors. First, it is the increased timber sourcing from secondary forests, fallows and farms as natural forest concessions move further away with corresponding increases in transport costs. Second, it is the reduction in illegal industrial logging due to improvements in transparency.

Poaching also greatly threatens biodiversity (Clarke & Rolf, 2013) and is rising **(Figure 2.1.14c)** given increasing demands for bushmeat, traditional medicine, souvenirs, pets and luxury goods (Hofer *et al.*, 1996). Poaching has pushed many species to the brink of extinction, even those in the IUCN's list of threatened species, e.g., rhinos and tigers.

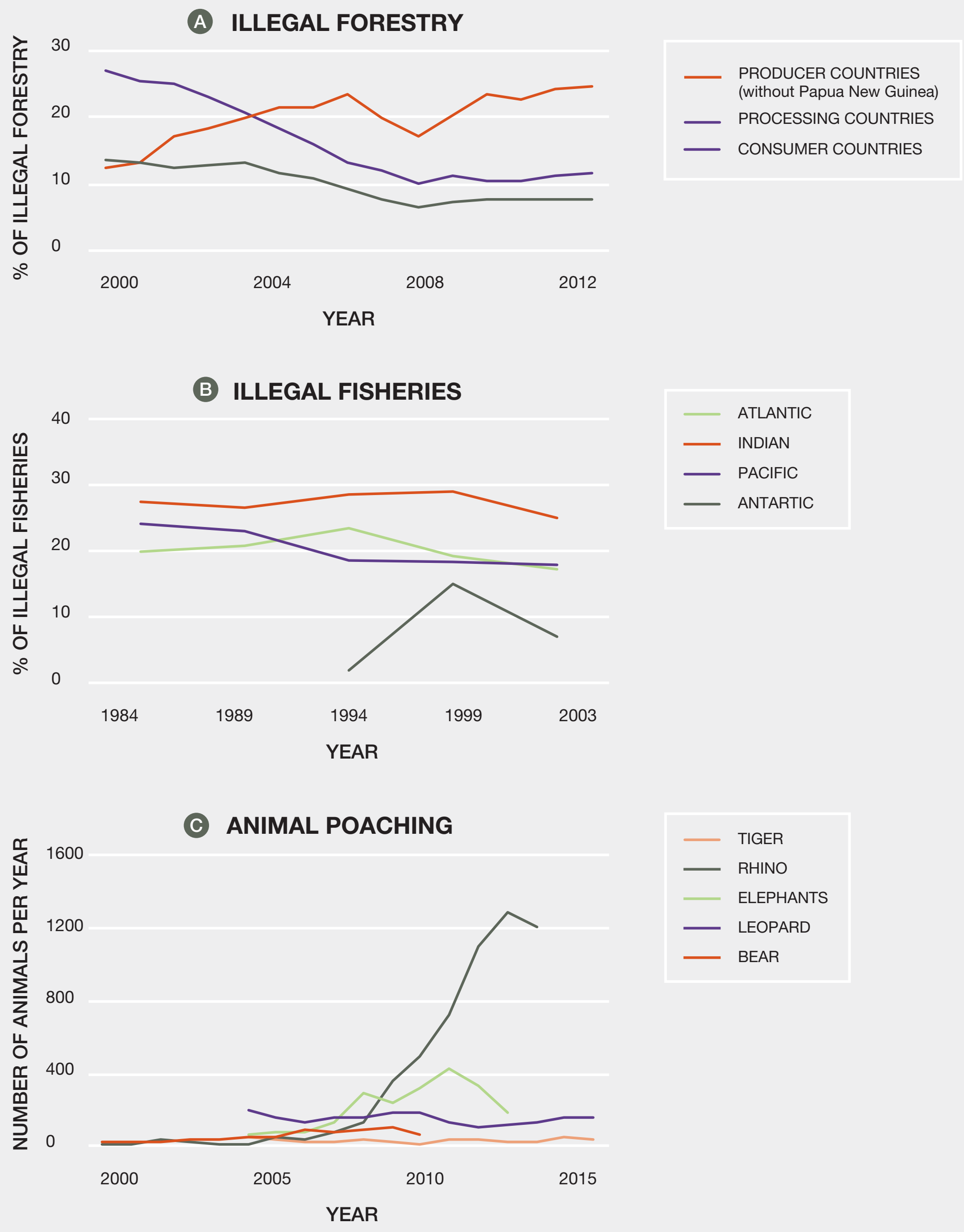


Figure 2 1 14 **Trends in illegal extractions from nature.**

A Producers, processers, and buyers of illegal wood: Percentage of total from 2000 to 2014, B Illegal fisheries: percentage of total fisheries that is illegal by region from 1984 to 2003, C Animal poaching: total number of animals per year from 2000 to 2017. Sources: Illegal forestry: Hoare (2015); Illegal fisheries: Agnew *et al.* (2009); Illegal poaching: data from the Wildlife Protection Society of India (http://www.wpsi-india.org/) for India only (Leopard/Tiger) and from http://www.poachingfacts.com/, reporting for some countries only and considering only years with consistent presence of data (Rhino/Elephant/Bear).

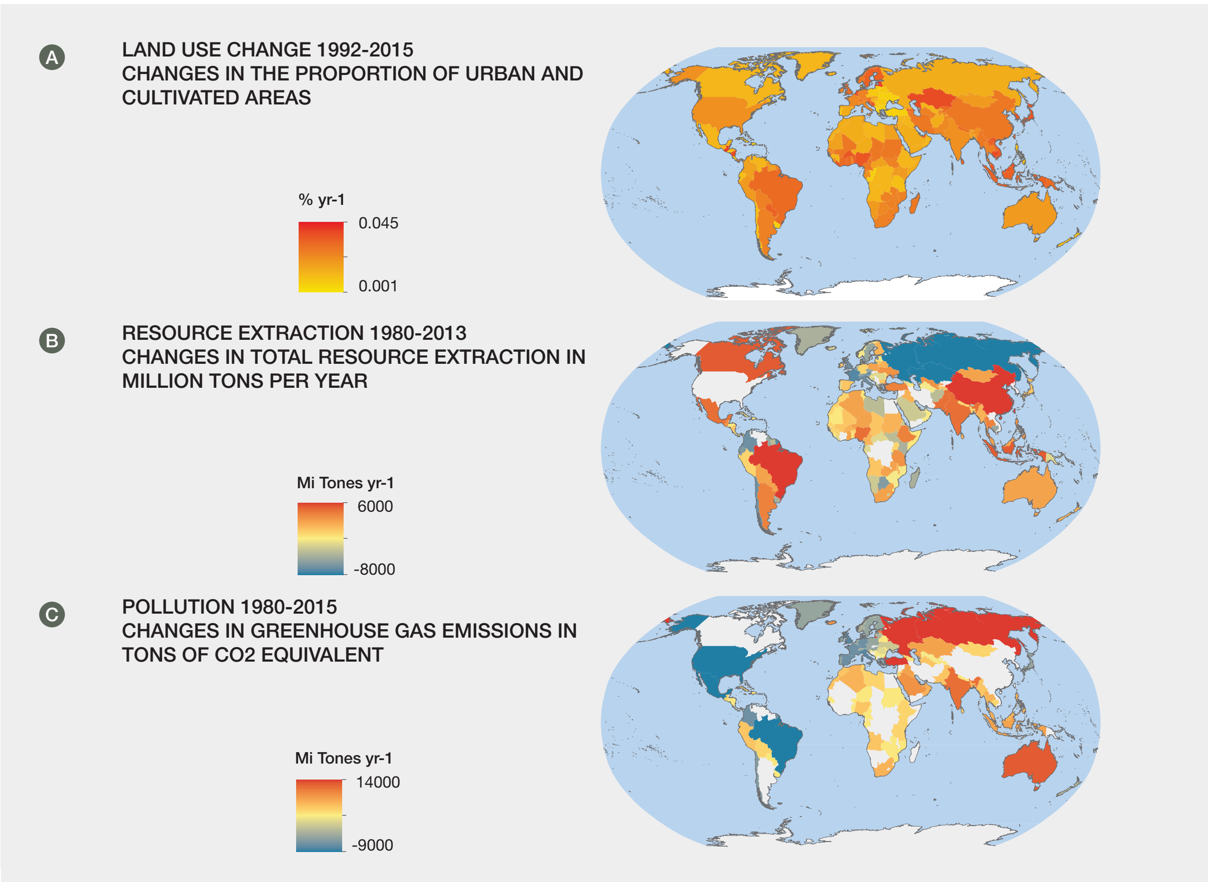
Various international organizations (e.g., WWF, IUCN) and agreements (e.g., CITES) include considerable efforts to eliminate poaching and countries (Kenya, Tanzania, South Africa) have taken drastic measures to control it and punish poachers, e.g., applying 'shoot-on-site' (Messer, 2010). While some of these mechanisms have slightly decreased poaching in many countries, it is still difficult to bust the invisible connections between the poachers and the recipients or users of animal parts.

Poaching has been promoted, to date, by several factors. Corruption, combined with different standards with respect to poaching bans, has greatly weakened law enforcement (Smith *et al.*, 2003). There is a lack of detection of tons of animal parts, or live animals, crossing political boundaries including international borders. Further, poor infrastructure, together with poorly equipped personnel engaged in trying to control poaching in many of the countries where it primarily takes place, reduces timely responses when a poaching incident is reported. But even when policy instruments officially are in place and their implementation is in fact being actively attempted, the lucrative financial gains for poaching driven by the high demand for animal parts and live animals have pushed poachers to discover innovative means of evasion (Knapp, 2012; Lindsey *et al.*, 2013; Milner-Gulland & Leader-Williams, 1992; Warchol & Kapla, 2012).

2.1.12 DIRECT DRIVERS OVERVIEW: AGGREGATING IMPACTS ACROSS SECTORS

Human actions to satisfy needs and goals – as above fisheries, agriculture, logging, harvesting, mining, infrastructure, tourism, transport, restoration – clearly affect nature quite considerably. Their aggregated impacts are classified in IPBES into five categories of direct drivers: land-use / sea-use change; resource extraction; pollution; invasive and alien species; and climate change. Each of these are addressed in independent sections below, with an introductory overview.

Overall temporal trends (**Figure 2.1.12**, maps in **Figure 2.1.15**, Figure S18 for IPBES regions) for the 5 categories of direct drivers show steady increases over the past five decades, across the planet, with differences across trends. Rates of land-use change are lower relative to several decades ago although still accelerating in selected countries, given urbanization, agriculture and grazing. Extraction of living biomass has increased overall, yet while some countries dramatically raised output, others did the opposite as they outsourced their demands. Pollution has diverse patterns. Total greenhouse gas



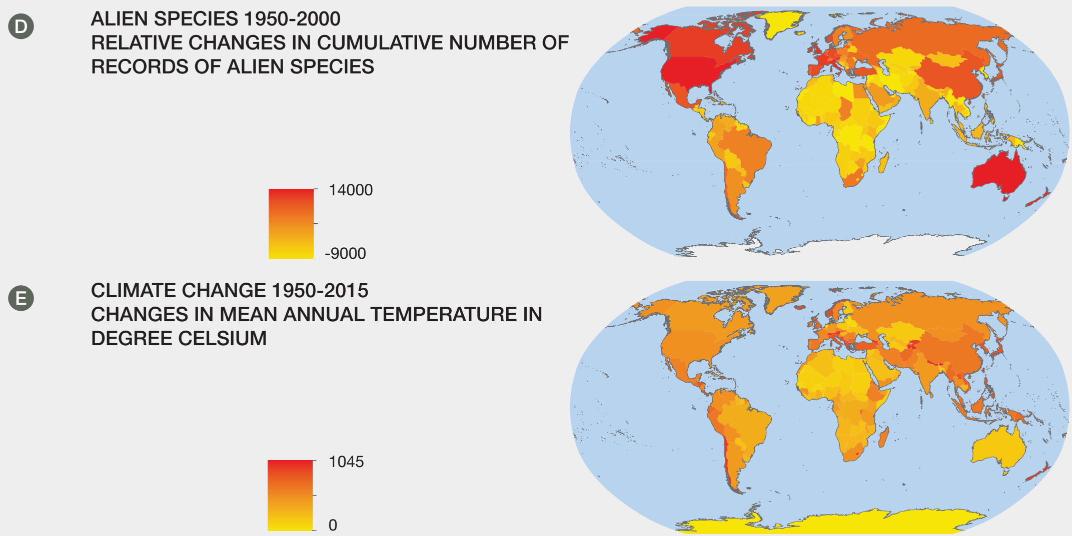


Figure 2 1 15 **Temporal trends per country for direct drivers**

A Land use change: changes in the proportion of urban and cultivated areas within each country calculated using country area data and Global Cover data 1992-2015 (see Chapter 2.2 for further details); B Resource extraction: changes in total resource extraction per year in million tons for 1980-2000, C Pollution: changes in greenhouse gases (CO2, CH4, N2O, CFCs, HFCs, PFCs, SF6, NF3) emissions in tons of CO_2 equivalent for 1980-2015. D Invasive alien species: changes in cumulative number of records of alien species for 1950-2005; E Climate change: changes in mean annual temperature in degree Celsius for 1950-2000 using Chelsa Climate Data. Sources: Hijmans et al. (2005), OECD (2018a), Ritchie & Roser (2018), Seebens *et al.* (2018), World Bank (2018p), WU (2015).

emission has doubled since 1980 (Figure S17, S27) while human-induced warming reached ~1°C (±0.2°C) above pre-industrial levels in 2017 (see section 2.1.17). While air pollution is highest for least developed and lower income countries, important decreases in the rates of emission of greenhouse gas emissions are observed in some of the developed and higher-income countries, due to increased awareness, as well as changes in policies linked to energy sources. Also, the increase is greatest for intermediate – but fastest growing – income levels, developing countries **(Figure 2.1.12)**, where population and income are increasing sharply. Alien species are escalating, especially for developed countries where the arrivals started earliest, and populations are both dense and dynamic. Current cumulative records of alien species are ~40 times larger in developed than in least developed countries. Though comparable across Europe and Central Asia, the Americas and Asia and the Pacific, they are ~4 times lower in Africa (Figure S29). Finally, while climate change is of course a global phenomenon, with global mixing of emissions, some countries are particularly challenged by the fastest rates of changes (see below – and also trends by units of analysis in chapter 2.2 complement this section).

Humanity's footprint has touched 75% of the terrestrial world and much of the oceans (Venter *et al.*, 2016). 25% of the world's terrestrial potential primary productivity has been appropriated largely through cropping and grazing (78% of the appropriation), followed by forestry, the construction of infrastructure, and human-induced fires (22%) (Krausmann *et al.*, 2013). Several biodiversity hotspots have been shown to present very small areas of no or low human footprint, as is the case of Western Australia, Tropical Andes, Northern Cerrado and Central Asian Mountains (Venter *et al.*, 2016). Lowest appropriation values (11–12%) are found in Central Asia, the Russian Federation, and Oceania (including Australia), while the highest ones are found in Southern Asia (63%), as well as Eastern and Southeastern Europe (52%).

A global map of anthropogenic impact on marine ecosystems (Halpern *et al.*, 2008) revealed that by 2007, around 40% of the world's ocean surface was affected by multiple drivers, such as changes in sea temperature, by-catch, habitat transformation, ocean acidification, and ocean pollution. An evaluation of the changes between 2008 and 2013 (Halpern *et al.*, 2015) revealed that more than 65% of the ocean experienced increases in cumulative impact during that period. Globally, increases in climate change related stressors, including sea surface temperature anomalies, ocean acidification and ultraviolet radiation, drove most of the increase in cumulative impact. Yet, impacts from most commercial fishing operations decreased in 70–80% of the ocean (Halpern *et al.*, 2015), confirming previous suggestions (Pauly *et al.*, 2002; Worm *et al.*, 2009) that global catch has stabilized or is declining in most parts of the ocean, and that well-managed fisheries are achieving sustainable yields.

2.1.13 DIRECT DRIVERS: LAND/SEA-USE CHANGES

2.1.13.1 Expansion of agriculture and cities

Over half the Earth's land surface is under cover types of anthropic origin, including agricultural lands, pasture and range lands, and cities (Foley *et al.*, 2005; Hooke *et al.*, 2012). Agricultural expansion is by far the most widespread form of land cover change, with over one third of the terrestrial land surface currently being used for cropping or animal husbandry at the expense of forests, wetlands, prairies and many other natural land cover types (FAO, 2016a; Foley *et al.*, 2005). Population growth (Nelson *et al.*, 2010), followed by urbanization and raising incomes, which are then linked to increasing per capita resource consumption (Liu *et al.*, 2003), clearly are major drivers of deforestation (Lambin & Meyfroidt, 2011).

Over five decades, the largest per cent changes in land use are associated with urban areas (**Figure 2.1.12**, **Figure 2.1.15**, Figure S24). City areas doubled in 1992–2015. The most severe increases were for tropical and subtropical savannas and grasslands, deserts and xeric shrublands, where the urban areas tripled.

Agricultural area increased by over 100 million hectares between 1980 and 2000 across the tropics, half at the expense of intact tropical forests (Gibbs *et al.*, 2010). Pasture for cattle contributed to the largest agricultural land expansion in Latin America, with an increase of ~35 million ha in South America and ~7 million ha in Central America (Gibbs *et al.*, 2010). In 1980–2000, cropland area increased by half in East Africa and a quarter in West Africa, while falling in Central Africa (Gibbs *et al.*, 2010). Africa lost the highest share of tropical forests in the 1980s, 1990s, and early 2000s (IPBES, 2018b). In Southeast Asia tree plantations occupy the largest share of agricultural land, which rose by 7 million ha in 1980–2000, while by the 1990s oil palm was responsible for over 80% of the expansion in tree plantations (Gibbs *et al.*, 2010). Timber extraction and fuelwood collection have also led to forest loss, while opening land for agriculture (Haines-Young, 2009; Hooke *et al.*, 2012). Yet, fuelwood collection is not a main driver, as it is based on collection of dry wood.

Deforestation rates are generally falling, with varying patterns across countries. China has seen high afforestation (FAO, 2015b), due to conservation and restoration over 30 years, in particular since 2000 (Viña *et al.*, 2016). In contrast, despite conservation policies in the 2000s (Macedo *et al.*, 2012; Nepstad *et al.*, 2014), Brazil continues to have significant deforestation (FAO, 2015b).

Other important drivers of the consequential expansion of agriculture – and shift in landscapes – include ongoing shifts toward animal-based diets (Alexander *et al.*, 2015; Rask & Rask, 2011) as well as the collapse of the Soviet Union, which triggered the abandonment of farms and, thereby, recoveries of prairies, woodlands and forests (Alcantara *et al.*, 2012; Bauman *et al.*, 2011; Hostert *et al.*, 2011; Ioffe *et al.*, 2012; Kuemmerle *et al.*, 2008), although some of the latter shifts were followed by a more recent re-cultivation in Southern Russia, Ukraine and Northern Kazakhstan (Meyfroidt *et al.*, 2013).

Following all of this, the global extent of wetlands has declined by 30% between 1970 and 2008 (Dixon *et al.*, 2016), and total loss has been estimated to be as much as 87% (IPBES, 2018a). Losses were greatest in the tropics and sub-tropics, where population growth and agricultural expansion were also highest (UNEP, 2016c). In the last two decades, peatland cover has reduced from 77% to 36% (Miettinen *et al.*, 2012). Peatlands are largely found in South-East Asia, which contains an estimated 56% of all of the tropical peatlands by area (Page *et al.*, 2011).

2.1.13.2 Fragmentation

Land-cover change has increasingly fragmented remaining land cover (see chapter 2.2). Currently, about 20% of the forest areas around the world are close (<100 m) to a forest edge, while 70% are within 1 km (Haddad *et al.*, 2015). Only 20% of tropical areas hold forest areas larger than 500 km^2 (Potapov *et al.*, 2017). The global extent of such areas decreased by 7.2% in the last decade (Potapov *et al.*, 2017), as a result of industrial logging, agricultural expansion, fire, and mining/resource extraction. The certification of logging concessions under responsible management had negligible impact in terms of slowing this fragmentation (Potapov *et al.*, 2017).

2.1.13.3 Landscape/seascape management intensification

Technological advances in agriculture, fisheries, aquaculture, and forestry over the last 50 years (see 2.1.5) led to increases in extraction, yields, and investments (in machinery and inputs), while often increasing the area of influence of these activities (farms or fishing grounds). The IPBES Land Degradation Assessment showed that intensive land use can lead to progressive changes in ecosystem functions and, in cases, irreversible changes then land abandonment (IPBES, 2018a).

Livestock density and herd management are the main causes of rangeland degradation, which can be exacerbated by changes in fire regimes and harvesting

(IPBES, 2018a). Asia has the most rapid grassland change (Akiyama & Kawamura, 2007). Agricultural intensification in regions has been linked to the stabilization or even reductions in agricultural land area, particularly for the sub-Saharan African region (Ausubel *et al.*, 2013; Brink & Eva, 2009; Lambin & Meyfroidt, 2011; Ramankutty *et al.*, 2006; van der Sluis *et al.*, 2016; van Vliet *et al.*, 2015; Wood *et al.*, 2004). When linked to subsistence agricultural production with low soil fertilities, low usage of agrochemicals, and low yields, this has led to reductions for natural land cover types (Brink & Eva, 2009; Wood *et al.*, 2004). Yet, agricultural intensifications have led to increases in yields that have come at the cost of an accelerated pollution of both soils and water (IPBES, 2018a)

2.1.13.4 Land degradation

Land degradation is the reduction or loss of biological or economic productivity and complexity (including soil erosion, deterioration in physical, chemical, biological or economic properties of soils and long-term loss of vegetation) of cropland, rangeland, pastureland forest and woodlands in arid, semi-arid and dry sub-humid areas, that results from land uses or form a combination of processes, including those arising from human activities and habitation patterns (IPBES, 2018a). Degradation is occurring in all land cover, land use and landscape types, in all countries (IPBES, 2018a). Degradation is hard to measure (Herold *et al.*, 2011; Houghton, 2012; IPBES, 2018a; Lambin, 1999), given a paucity of data and the absence of estimates, especially in the tropics (Houghton, 2012). Degradation is driven by multiple drivers including land use change, intensification, pollution, and invasive alien species, many distant from where impacts are felt (IPBES, 2018a). Loss in forests, for example, are linked to uncontrolled logging (Tacconi, 2007b), fires, agricultural expansion (Lawrence, 2005; Van Vliet *et al.*, 2012) and also charcoal (Ahrends *et al.*, 2010; Chidumayo & Gumbo, 2013). Most prominent in Latin America and Asia is timber extraction while, in Africa, it is fuelwood and charcoal (48%) (Hosonuma *et al.*, 2012; Kissinger *et al.*, 2012). Desertification, i.e. land degradation in arid, semi-arid and dry sub-humid areas, is particularly severe for 38% of the world's population, including pastoralists and smallholder farmers tending lands disproportionately vulnerable to degradation (IPBES, 2018a).

Soil degradation includes loss of soil as well as changes in its physical, chemical and biological properties (IPBES, 2018a). Erosion causes nutrient loss (Lal, 2014) and reduction of agricultural productivity, plus flooding, water pollution and sedimentation of reservoirs (Munodawafa, 2007; Rickson, 2014). Erosion may also negatively affect the global carbon, nitrogen and phosphorus cycles (Chen *et al.*, 2010b; Quinton & Catt, 2007). Indeed, soil organic carbon, has fallen globally from land conversion and unsustainable land management practices (IPBES, 2018a). Reliable global estimates of the magnitude and extent of soil erosion are unavailable but its occurrence in all countries can be confirmed (IPBES, 2018a).

Soil acidification is associated with atmospheric deposition of strong acids (acid rain), as a result of emissions of sulfur dioxide and nitrogen oxides exacerbated by anthropogenic activities. Acid deposition on poor soils covered by temperate forests (Driscoll *et al.*, 2001; Greaver *et al.*, 2012), forest and crop harvesting (especially if frequent) (Likens *et al.*, 1998) and loss of nutrients due to rain and irrigation (leaching) (Lawrence *et al.*, 1987) can all exacerbate its effects.

Global soils in over 100 countries are affected by salinity, linked to climate change and increased use of irrigation for production of crops (Squires & Glenn, 2009). Salinity occurs naturally, yet it is often exacerbated by irrigation at rates not adequate to exceed evapotranspiration rates (FAO & ITPS, 2015), by poor drainage or groundwater levels near the soil surface (< 2m), by the use of brackish water to irrigate, by intrusion of seawater near coastal areas, and by shifts from deep rooted perennial vegetation to shallow rooted annual crops and pastures (FAO & ITPS, 2015).

2.1.14 DIRECT DRIVERS: RESOURCE EXTRACTION

2.1.14.1 Rates of extraction of living and nonliving materials from nature

Extraction of living biomass and nonliving materials is increasing as both populations and per capita consumption **(Figure 2.1.4, Figure 2.1.12, Figure 2.1.15)** increased sixfold from 1970 to 2010, while the demand for materials used in construction and industry quadrupled during that time.Materials for construction and industry increased 4-fold, with the most dramatic increases for lower-middle (7-fold) and upper-middle income countries (11-fold) and the Asia and the Pacific region (10-fold for whole region) (Robinson & Bennett, 2004; Schandl & Eisenmenger, 2006; Schandl *et al.*, 2016) and, generally, the growing economies (Figure S18, Figure S25, Figure S26). The use of biomass, fossil fuels, metal ores and non-metallic minerals doubled from 2005 (26.3 billion tons) to 2015 (46.4 billion tons), growing an annual rate of 6.1%.

Yet extraction rates varied widely by country, barely increasing in Africa since 1970 (Schandl *et al.*, 2016). The global shares for Africa, Latin America and the Caribbean, and West Asia were relatively constant over four decades, with all growing in total volume, while Europe and North America fell sharply in terms of their global shares of direct extraction (Schandl *et al.*, 2016). These differences may reflect sectoral shares (see above), as extraction for agriculture, forestry, fishing, hunting only doubled in 50 years but construction and industry rose more (WU, 2015).

Cascading effects of extraction can be manifested as biodiversity losses and accelerated changes in climate (Butchart *et al.*, 2010), most prominently in tropical forests, marine, coastal and polar ecosystems (Bradshaw *et al.*, 2009; Geist & Lambin, 2002). Some types of extraction also result in land-use change, with consequences for biodiversity, soil erosion and degradation, GHG emissions, and potential loss of an array ecosystem services (Geist & Lambin, 2002).

Extraction beyond sustainable levels has consequences for biological dynamics and ecosystem function. Yet assessing what levels of extraction of resources are sustainable is very complex, as species- and context-specific efforts are needed. Impacts of overexploitation can be observed in life histories, genetic patterns of populations, and community and ecosystem functions (Ticktin, 2004). Wildlife extraction through hunting from tropical forests, for instance, is estimated to be well above the sustainable rate (Bradshaw *et al.*, 2009) and for terrestrial species, exploitation (26%) is the second most common threat preceded only by habitat loss (50%) (WWF, 2016).

2.1.14.2 Freshwater withdrawals

Freshwater resources are unevenly distributed. About one third of the Earth's land subsurface is underlain by relatively homogenous aquifers (exclude the Antarctic), often in large sedimentary basins with suitable conditions for groundwater exploitation (WHYMAP & Margat, 2008). Asia (30.72%) harbors most of these aquifers, followed by Africa (28.48%), Central/South America (17.64%), Europe (10.88%), North America (6.78%) and Oceania (5.49%). Most of the largest global aquifer systems are found within Africa (35%), followed by Asia (27%), the Americas (22%), Europe (11%) and Oceania (5%) (Richey *et al.*, 2015; WHYMAP & Margat, 2008).

Global water withdrawals are hard to calculate, as their estimation depends upon reliable data at the local and country level, yet reliable data are limited to a few countries. Estimations by FAO suggest that water withdrawals have risen from less than 600 km^3/year in 1900 to nearly 4,000 km^3/year in 2010, faster than population growth (FAO, 2011c). The surface waters of key river basins such as the Colorado, the Huang-He (Yellow River), the Indus, the Nile, the Syr Darya, and the Amu Darya are heavily used (WRI, 2000) and 21 of 37 aquifers have exceeded their 'sustainability tipping points' during 2003–2013 (Richey *et al.*, 2015). Increased groundwater extraction has been attributed to agricultural use (69%), industrial use (19%) and direct human consumption (12%) (FAO, 2011c; Wada *et al.*, 2014) with growing populations, industries and, more generally, economies (Alcamo *et al.*, 2003; FAO, 2011c; Mekonnen & Hoekstra, 2011).

Depletion of water resources interacts with many biophysical and societal drivers to contribute to negative impacts on nature and societies. Withdrawals, with climate change, lower mean annual run-off across river basins in Asia and America (Haddeland *et al.*, 2014), as well as water quality (Navarro-Ortega *et al.*, 2015). Depletion threatens water and food security, alters hydrological regimes (Arroita *et al.*, 2017), induces land degradation (Dalin *et al.*, 2015), and conflicts (Richey *et al.*, 2015). Threats from excessive extraction are pronounced in arid and semi-arid regions (Haddeland *et al.*, 2014). Irrigated agriculture leads to drastic effects on wetlands and wildlife conservation (Lemly *et al.*, 2000).

Facing scarcities, improved agricultural and water management practices have been developed to reduce water stress. Successful cases involving smallholder farmers have received considerable attention in recent years. In those involving Indigenous Peoples, land and water management have been integrated (Critchley *et al.*, 2008) – suggesting that improvements are possible despite decreasing aggregate resource availability at global scales (Pretty *et al.*, 2000).

2.1.15 DIRECT DRIVERS: POLLUTION

Quantitative assessments of pollution are limited to a few systematically monitored variables – with inconsistent data quantity and quality across countries. The most robust available data are from remote monitoring, including greenhouse gas emissions and the presence of aerosols (i.e., particulate matter). Country data on access to improved sanitation (e.g., municipal waste or use of pesticides or fertilizers) is available (FAO, 2018a, 2018d; OECD, 2018b; Ritchie & Roser, 2018; World Bank, 2018h), although again with varied data quantity and quality. Significant emissions into the atmosphere, water bodies, and terrestrial systems from industrial activities and households remain unquantified. Yet, currently available data on related metrics suggest that the global pollution levels have increased at rates at least comparable to the total population growth.

2.1.15.1 Emissions into the atmosphere

Population growth, economic activity, energy consumption and technology drive anthropogenic greenhouse gas (GHG) emissions – such as carbon dioxide (CO_2), nitrogen oxide (NO_x), and sulphur dioxide (SO_2) – that trap heat in the atmosphere and contribute to global climate change. Emissions from transportation contribute GHGs and conventional air pollutants and particulates (UNEP, 2016e). Smaller particles (PM 2.5) are important threats to human health (WHO, 2016). GHG emissions have risen consistently, combining them with small particles, all countries show increases in air pollution (**Figure 2.1.12**, Figure S27, Figure S28). Largest increases are found in Northern Africa, Central Asia, and East Asia – due to a lack of regulations as well as to geological and climatic factors.

Some countries have sharply increased CO_2 emissions since 1980, while others reduced them (Figure S28). Europe and the Central Asian region reached peak CO_2 emissions in 1990, steadily decreasing since then. The Asia and the Pacific region has surpassed Europe and America to become the largest emitter of CO_2 since 2004. Major CO_2 producing regions are the United States (15%), the European Union (10%) and India (6.5%), which with China account for 61% of the total global emissions (Olivier *et al.*, 2015). CO_2 emissions increased on average (14%) in Latin America and the Caribbean, from 2006 to 2011 (UNEP, 2016d; World Bank, 2017c). During 2000–2010, Africa, Asia and the Pacific, Latin America and North America increased 15% in methane emissions (UNEP, 2016d). Thus, while GHG emissions are driven by economic development, displacement of production and extraction by trade allows for emissions, in some cases, to have fallen for higher incomes while increasing for lower incomes.

The reduction in GHG emissions in developed countries is actually a transference of GHG to developing countries, referred to as "GHG leakage", through international trade, which accounts for ~30% of CO_2 emissions (see also 2.1.6.3.2) (Aichele & Felbermayr, 2015; Kanemoto *et al.*, 2014). In fact, higher-income countries did not actually reduce emissions, but just shifted them. For instance, during the 1990–2011 period, developed countries reduced emissions by 1.59 Gt while developing countries increased emissions by 13.7 Gt. However, after assessing the CO_2 leakage by assigning responsibility to consumers, in 2011 developed countries transferred 2.95 Gt of CO_2 to developing countries through trade (Kanemoto *et al.*, 2014). Developed countries shifted their non-CO_2 GHGs emissions to developing countries even more strongly than they did for CO_2.

Emissions of nitrogen oxides ($NO_{x)}$ are associated with roads transport, energy production, and many commercial, institutional and household activities. NO_x emissions contribute to acid deposition and eutrophication and have drastically increased. Asia, including the Middle East, accounts for ~30% of the global emissions. NO_x emission levels have decreased in the US and in Western Europe, while increasing in Africa over the last decade (Figure S28; EEA, 2014; UNEP, 2016b).

Emissions of SO_2 from the combustion and oxidation of fuels and other materials have risen due to industry and shipping. Asia showed an increasing trend since 2000, contributing 41–52% of global emissions, while emissions from North America and Europe declined from 38% to 25%. SO_2 emission from industry increased from 32% to 38%, while those from international shipping increased from 9% to 25% over the last decade (Klimont *et al.*, 2013) as trade rose.

Emissions of particles into the atmosphere ($PM_{2.5}$ -particles smaller than 2.5 micrometers) are highest in least developed countries **(Figure 2.1.12)** and in high income oil producing countries (Figure S28). Northern Africa has highest $PM_{2.5}$ emissions (De Longueville *et al.*, 2014; Van Donkelaar *et al.*, 2010). Emissions due to residential energy use, such as heating and cooking, are prevalent in India and China. Those from traffic and power are high in the US (Lelieveld *et al.*, 2015).

Higher levels of exposure of human population to air pollution within lower-income countries, especially in Northern Africa and Central Asia, can be attributed to climatic / geological factors (arising from, e.g., dust and storms), predominant energy sources, and agricultural emissions (Lelieveld *et al.*, 2015). Additionally, another important factor is the fact that dirtier phases of industrial processes are exported to lower income countries with reduced regulations and enforcement (see also 2.1.6.3.2).

Other airborne contaminants also have had major impacts on nature and people. Mercury enters the atmosphere from volcanoes, and coal burning, then is transported to areas such as the Artic, with a 10-fold increase in upper-trophic-level mammals such as beluga whales, over the past 150 years (AMAP, 2018). Global emissions of nitrogen from synthetic fertilizers and the expansion of nitrogen-fixing crops are several orders of magnitude larger than pre-industrial levels (Vitousek *et al.*, 1997a).

Noise's effects on nature are increasingly observed. Expansions of human populations, transport networks and extraction have a range of impacts upon species, depending on auditory capacities (Shannon *et al.*, 2016) and noise wavelengths (Todd *et al.*, 2015). Underwater noises that are due to shipping are significant marine pollutants (Williams *et al.*, 2015). Behavioural changes for both individuals and entire ecological communities have been observed in response to a wide range of noise sources and exposure levels (Shannon *et al.*, 2016; Todd *et al.*, 2015; Williams *et al.*, 2015).

2.1.15.2 Contaminants dissolved in/carried by water

Water quality has fallen over the last five decades, with key environmental and societal impacts. Major sources include untreated urban sewage and industrial and agricultural run-off, erosion, airborne pollution, and salinization, as well as oil spills and dumping of substances into the oceans. It is estimated that over 80% of urban and industrial wastewater is released to freshwater systems without adequate treatment, a volume six times as large as that in all of the world's rivers, i.e., 300–400 million tons of contaminants (UN, 2003; UN-Water, 2015; WRI, 2017; WWAP, 2012).

One available indicator on water quality is that of access to improved sanitation facilities which shows very contrasting patterns among countries with different income levels, as 60% of the population in low income countries do not have access to such facilities (World Bank, 2018m). Over 600 million people lack access to safe drinking water, nearly half in Africa, followed by Asia, then Latin America and the Caribbean (WHO-WEDC, 2013). Large regional variance in wastewater treatment includes 70% in Europe but as low as 20% in Latin America (Sato *et al.*, 2013). Untreated urban wastewaters dumped into the environment (Beketov *et al.*, 2013; Malaj *et al.*, 2014; Moschet *et al.*, 2014; Stehle & Schulz, 2015; Van Dijk *et al.*, 2013) contain fecal coliforms, organic pollutants (UNEP, 2016b, 2016c, 2016d, 2016e, 2016f), heavy metals, and pharmaceutical residues (Cleuvers, 2004; Santos *et al.*, 2010; Wilkinson *et al.*, 2016).

About a quarter of the rivers in Latin America, 10–25% in Africa and up to 50% in Asia have severe pathogen pollution, largely caused by untreated wastewater (UNEP, 2016a). More than 200 types of molecules derived from pharmaceutical processes have been measured in natural waters (Pal *et al.*, 2010; Petrie *et al.*, 2015), frequently anti-inflammatory drugs, antiepileptic, contraceptives or antibiotics. These impair organisms in rivers (Brodin *et al.*, 2014) and in estuarine and marine waters (Guler & Ford, 2010; Kidd *et al.*, 2007; UNESCO & HELCOM, 2017). Human health and nature concerns also include chemicals like dissolved metals (zinc, copper, aluminum) or surfactants, whose risks to aquatic ecosystems remain high even within higher-income countries (Johnson *et al.*, 2017).

Agriculture causes most soil erosion and nutrient run-off to freshwaters (Quinton *et al.*, 2010). Fertilizers used in crop production are also drained into continental, coastal and marine water bodies at accelerating rates (Figure S21), with nitrogen fluxes (mainly as nitrate) rising 4- to 20-fold in the last decade (Camargo & Alonso, 2006; Mekonnen *et al.*, 2015). Nutrients from fertilizers in continental water bodies flow into coastal waters, stimulating excessive plant growth and, in extreme conditions, hypoxia or oxygen-depleted "dead zones" plus harmful algal blooms that affect primary and secondary productivity (Altieri *et al.*, 2017). By 2008, 494 coastal dead zones were listed. Pesticides, agricultural insecticides, and newer generation molecules (like pyrethroids and neonicotinoids) (Stehle & Schulz, 2015) reduce macroinvertebrate richness in rivers by up to 40% (Beketov *et al.*, 2013; Van Dijk *et al.*, 2013), while urban and agricultural herbicides exert effects on non-target species like algae (Malaj *et al.*, 2014; Moschet *et al.*, 2014). Ecotoxic chemical micropollutants, including pesticides, pharmaceutical residues, plastics, and dissolved metals all exert chronic effects and have endocrine disruptive properties that affect freshwater biodiversity and jeopardize the health of water ecosystems (Beketov *et al.*, 2013; Malaj *et al.*, 2014; Moschet *et al.*, 2014; Stehle & Schulz, 2015; Van Dijk *et al.*, 2013).

Lower water quality has led to severe changes in the ecohydrology of water systems (Carpenter *et al.*, 2011). In the past decade, the trend of deterioration has shifted from developed to developing countries, with increasing population and economic activity (UNEP, 2016a). The Water Quality Index (WATQI), an index ranging from 0 (worst) to 100 (best) that combines five parameters (pH, dissolved oxygen, total phosphorus, nitrogen concentrations, electrical conductivity) was 69.21 in 2012, globally, with the highest values in Europe (80.38), then Oceania (79.19), the Americas (76.59), Asia (76.59) and Africa (57.74) (Srebotnjak *et al.*, 2012). Climate change, hydrologic flow modification, land-use change, and aquatic invasive species interact with other drivers of water pollution (Carpenter *et al.*, 2011; UNEP, 2016a) to help explain this significant spatial variation.

Marine water quality is strongly affected by oil spills and the dumping of toxic compounds. Oil spills, toxic for marine life and difficult to clean up, are a major contamination source. In 1990, 1.1 million tons of oil was lost via spills. As technologies and policies have improved, by 2015 the magnitude was ~25,000 tons. Yet spills still contribute over 10% of oils entering the oceans (Anderson, 2013). Marine pollution is also affected by dumping and dumping bans (UN, 2017). Authorities are paying more attention to "black" lists of substances that should not be dumped (toxic organohalogen compounds, carcinogenic substances, mercury and cadmium), as well as "grey" lists (e.g. arsenic, lead, copper and zinc and their compounds, organosilicon compounds, cyanides, fluorides and pesticides) (IMO, 1972). In 2003–2012, the total chemicals entering seas rose by 12%, down 60% in North America and Europe but up 50% in the Pacific (UN, 2017).

Emissions of NO_x have acidified freshwater ecosystems (Skjelkvåle *et al.*, 2001; Stoddard *et al.*, 1999). Lakes and streams of eastern North America and Northern and Central Europe are highly acidified, with pH values ranging from 4.5 to

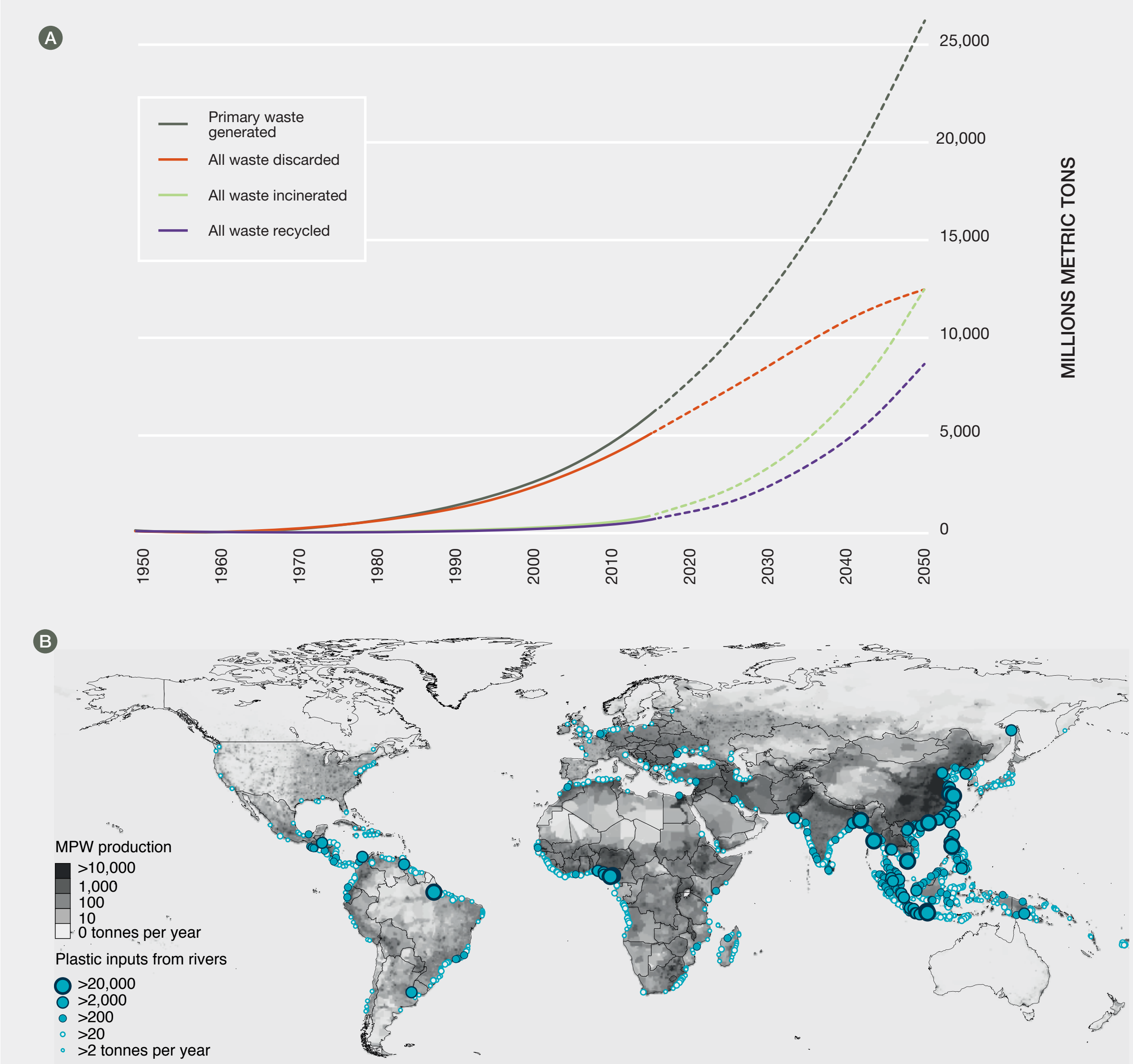


Figure 2 1 16 **Plastic waste production and flow into global oceans.**

A Trend of cumulative plastic waste generation and disposal (1950~2050); B Mass of river plastic flowing into oceans in tonnes per year; river contributions are derived from individual watershed characteristics such as population density, mismanaged plastic waste (MPW) production per country and monthly averaged run-off; the mode is calibrated against river plastic concentration measurements from Europe, Asia, North, and South America. Source: Geyer *et al.* (2017), Lebreton *et al.* (2017).

5.8 (Doka *et al.*, 2003; Skjelkvåle *et al.*, 2001). Further, salinity levels rose nearly one third in Asia, Africa and Latin America between 1990 to 2010. Severe and moderate salinity levels affect one in 10 rivers in these three continents, making it harder for poor farmers to irrigate their crops (UNEP, 2016a).

2.1.15.3 Disposal or deposition of solids

Solid wastes are increasing, globally, although it is uncertain by how much as systematic solid-waste accounting often remains a challenge. Solid waste is mostly generated in and disposed of in cities. Waste is larger in urban areas, correlated with purchasing power (Hoornweg *et al.*, 2013). Cities produce 1.3 billion tons of solid wastes, per year, for instance. Municipal waste per capita has doubled over the last decade (Hoornweg & Bhada-Tata, 2012).

Solid wastes have impacts at different scales. For neighborhoods, ill-managed waste contributes to respiratory ailments, diarrhea and dengue fever, sewage blockages and therefore local floods (Hoornweg & Bhada-Tata, 2012). At the regional and global scales, solid waste emits methane, contributing to climate change, and produces leachates which contaminate the soils and aquifers. Every type of disposal (incinerating, recycling, downcycling) produces adverse environmental impacts, e.g., all of them contribute to GHG emissions in different ways. Solid waste disposal accounts for almost 5% of the total global GHG emissions (Hoornweg & Bhada-Tata, 2012).

Globally, the composition of waste is changing. Waste that is environmentally and economically costly to dispose has been increasing, while organic waste is decreasing. Yet, regional variation is significant. For example, electronic waste composed of both hazardous wastes and strategic metals (rare earth materials), which have to be separated to be properly disposed of or recycled, is the fastest growing type (UNEP, 2012). Electronic waste management is poorly regulated too, accumulating in landfills and often exported to lower-income countries. Recycling by informal sectors has had negative health effects (Ongondo *et al.*, 2011; UNEP, 2012).

Plastic pollution is escalating, and it is accumulating in the oceans at alarming rates **(Figure 2.1.16)**. Global production of plastic resins and fibers rose at an annual rate of 8.4% from 1950 to 2015, over twice as faster as GDP (Geyer *et al.*, 2017). Perhaps 5% ends up in oceans due to inadequate waste management (Jambeck *et al.*, 2015). Globally, 1.15–2.41 million tons of plastic currently flow from riverine systems into oceans every year (Jambeck *et al.*, 2015; Lebreton *et al.*, 2017; UNEP, 2016a). The top 20 polluting rivers were mostly in Asia and accounted for two thirds of global annual input (Lebreton *et al.*, 2017), while the top 122 polluting rivers contributed over 90% of inputs – and are still largely in Asia, with a few in Africa, plus South and Central America, and one in Europe (Lebreton *et al.*, 2017). Besides rivers, plastic wastes enter via mismanagement in coastal regions (Hoornweg & Bhada-Tata, 2012; Jambeck *et al.*, 2015).

On average, every square kilometer of ocean has 63,000 microplastic particles on its surface (Eriksen *et al.*, 2014; Isobe *et al.*, 2015). Much of it is within the five sub-tropical ocean gyres, where ocean currents cycle and gather marine debris. East Asian seas show concentrations 27 times the average, followed by the Caribbean and the Mediterranean (Law *et al.*, 2010). Plastic is also accumulating along the shorelines (UNEP, 2016a). The ratio of plastic to fish by weight in the oceans was 1:5 in 2014 (Ellen MacArthur Foundation, 2013).

Plastic fragments are a particular concern, as they are difficult to remove from the environment and can be ingested (Barnes *et al.*, 2009), affecting at least 267 species including 86% of all marine turtles, 44% of all seabird species, and 43% of all marine mammals (Derraik, 2002; Laist, 1997). This can affect humans through food chains. For instance, 25% of fish sold for human consumption in a Californian market were found to have microplastics debris (Rochman *et al.*, 2015). Beyond macro- and micro-plastics, plus persistent organic pollutants (POPs; Mato *et al.*, 2001), non-indigenous species (Barnes, 2002) and algae linked with red tides (Masó *et al.*, 2003) are transported with plastics (Barnes *et al.*, 2009), while concerns exist about discarded fishing gear (Gilman *et al.*, 2016).

2.1.16 DIRECT DRIVERS: INVASIVE ALIEN SPECIES (IAS)

Nearly one fifth of the Earth's surface is at risk of plant and animal invasions – including many biodiversity hotspots (IPBES, 2018a). Alien species doubled in the last 50 years (**Figure 2.1.12**, **Figure 2.1.15**, Figure S29; chapter 2.2; chapter 3) and threaten native species and ecosystem services (Capinha *et al.*, 2015; Simberloff *et al.*, 2013; Vilà *et al.*, 2010) as well as economies and human health (Kettunen *et al.*, 2009; Pyšek & Richardson, 2010; Vilà *et al.*, 2010).

The cumulative number of alien species that have been recorded is ~40 times greater within the developed than within least developed countries, due in part to trade and population but also to detection capacities (**Figure 2.1.4**, **Figure 2.1.6**, **Figure 2.1.9**, Figure S29) (Seebens *et al.*, 2017, 2018). While the current recorded levels of alien species in Europe and Central Asia, the Americas, and Asia and the Pacific are all similar, levels are lower in Africa. (Figure S29) (Seebens *et al.*, 2017, 2018). The number of alien species recorded is not equivalent to the number of IAS, as no estimates of invasibility are available and that can vary dramatically across alien species.

IAS hotspots are often in developed countries within North America, Europe and Australasia (Dawson *et al.*, 2017). The number of established alien species, and also their rates of invasion, have risen during the last century (Aukema *et al.*, 2010; Blackburn *et al.*, 2015; Lambdon *et al.*, 2008). In addition, the rate of emerging alien species – never encountered before as aliens – is high, with one quarter of first records in 2000–2005. The rate of introduction of new IAS seems higher than ever before and with no signs of slowing (Seebens *et al.*, 2017, 2018).

Major drivers of invasions are expansions of trade networks, higher human mobility, continuous habitat degradation and climate change. The latter exacerbates nitrogen deposition and increases fire frequency (Aukema *et al.*, 2010; Early *et al.*, 2016; IPBES, 2018a; Seebens *et al.*, 2018). The eradication of established IAS is very expensive (IPBES, 2018a; see more in chapter 2.2).

2.1.17 DIRECT DRIVERS: CLIMATE CHANGE

Climate change is currently a major driver of change in nature, with strong direct global impacts, that also affect impacts of other drivers. Unprecedented rises in atmospheric concentrations of GHGs (namely carbon dioxide, methane and nitrous oxide) across at least the last 800,000 years (IPCC, 2014), are extremely likely to have been the dominant cause of observed warming trends worldwide (IPCC, 2014). Natural variations in global temperatures are considered to be low, as compared to such human-induced warming. The latter is growing beyond a threshold that could not have been otherwise exceeded through natural variation (Herring *et al.*, 2016; IPCC, 2014).

Human-induced warming reached ~1°C (±0.2°C) above pre-industrial levels in 2017, with rises of 0.2°C (±0.1°C) per decade (IPCC, 2018)**.** Impacts include thermal stress, coral bleaching, and melting of sea and land ice (IPCC, 2013). The highest velocities in temperature change are found in flat landscapes and at higher latitudes (Loarie *et al.*, 2009). Most land regions are warming faster than the average, most ocean regions slower (UNFCCC, 2015). Evidence of long-term geophysical and biological changes due to warming is now more clear in many parts of the world – such as in the retreat of mountain glaciers, the earlier arrival of spring (Smit *et al.*, 2001), and changes in the phenological responses of vegetation (Root *et al.*, 2003)and in primary productivity (Lucht *et al.*, 2002). Changes in precipitation have also occurred. Areas in tropical regions have exhibited increased precipitation while areas in subtropical regions have exhibited decreased precipitation (Rummukainen, 2012). Precipitation has decreased more drastically in Northern and Central African Countries and Western Asia (Hijmans *et al.*, 2005).

Climate models have assessed impacts of anthropogenic forcing described above on increases in the frequencies and intensities of extreme events (King *et al.*, 2015) – e.g., heat waves, droughts, heavy rainfall, storms and coastal flooding (IPCC, 2018; McBean, 2004; Mitchell *et al.*, 2006) (see chapter 4 for further details). These events result from sporadic weather patterns (Luber & McGeehin, 2008) and they can be intensified by climate variability (e.g., due to El Niño/Southern oscillation) (Cai *et al.*, 2015; L'Heureux *et al.*, 2016; Newman *et al.*, 2018; Weller *et al.*, 2016). The increase in the frequency and intensity of such extreme events has been linked to considerable effects on well-being, with losses of life, injuries, and also other negative health effects, together with damages to property, infrastructure, livelihoods, service provision and environmental resources (UN, 2016c). In particular, important increases in the frequency and intensity of devastating hurricanes have been projected (Bender *et al.*, 2010; Emanuel, 2017; Knutson *et al.*, 2010; Ornes, 2018; Risser & Wehner, 2017).

The effects of all of these changes – temperature, precipitation, and frequency and intensity of extreme weather events – can accumulate and interact for further unexpected nonlinear change, with perhaps irreversible impacts on nature and nature's contributions to people and to society – including economic growth and food and water security (Burke *et al.*, 2015; Franzke, 2014; Friedrich *et al.*, 2016; Hegerl *et al.*, 2011; Schneider, 2004). Climate-driven changes can interact with other direct drivers, at times exacerbating impacts on nature and society (IPBES, 2018b, 2018a). Interactions of climate with other factors could also initiate nonlinear climate responses, yielding more extreme and/or rapid effects of climate change (Mitchell *et al.*, 2006).

2.1.17.1 Sea-Level Rise

From 1901 to 2010, the global sea level rose by 0.19m (0.17 to 0.21m), with an ongoing rate of rise of over 3 mm yr^{-1} across recent decades. This rate of sea-level rise (SLR) is faster than that experienced across the previous two millennia, and is likely to continue or accelerate (Alverson, 2012; IPCC, 2014). The increase in global temperature has a direct linkage with SLR (Church *et al.*, 2006), as SLR results from ocean thermal expansion, with reductions in the glaciers and the Greenland and Antarctic ice sheets (Cazenave & Cozannet, 2014; IPCC, 2014).

SLR is not homogeneous. In 1993–2012, the western Pacific Ocean exhibited a rate of SLR three times higher than the global mean, while much of the west coast of the Americas had a sea level reduction (Cazenave & Llovel, 2010; Stammer *et al.*, 2013). SLR is, in turn, a contributor to climate change acceleration (Galbraith *et al.*, 2002; Goodwin, 2008), and the increased severity of storm-surge events (Church *et al.*, 2008; Nicholls & Cazenave, 2010). Low-lying coastal areas, including many cities, beaches and wetlands are the most vulnerable to flooding and land loss from SLR (Nicholls & Cazenave, 2010; Sallenger *et al.*, 2012), with the total threats being the highest in densely populated areas (Stammer *et al.*, 2013). For instance, most countries in South, Southeast, and East Asia are highly vulnerable to SLR because of the widespread occurrence within those regions of very densely populated deltas, while a number of countries in Africa are highly threatened due to low levels of development combined with rapid population growth rates in coastal areas (Nicholls & Cazenave, 2010).

2.1.17.2 Ocean Acidification

Ocean acidification also drives loss in coastal and marine ecosystem services. In most cases, it is generated by anthropogenic CO_2 emissions (Doney *et al.*, 2009). Acidification results in biochemical alteration of salt water ocean ecosystems (Doney *et al.*, 2009). Current acidity is estimated to be the highest since the extinction of dinosaurs 65 million years ago, above levels experienced at least over 800,000 years (Lüthi *et al.*, 2008). Acidification is most critical for the shallow-water areas over-saturated with calcium carbonate. The highest concentrations of anthropogenic CO_2 are in near-surface waters, as mixing of these waters into the deeper oceans can take centuries. About 30% of the anthropogenic CO_2 is at depths shallower than 200 m, while nearly 50% is at depths shallower than 400 m (Feely *et al.*, 2004). The pH has fallen more than 30% since the industrial revolution, with a massive threat to marine biodiversity (Hoegh-Guldberg & Bruno, 2010). Highest concentrations of anthropogenic carbon in the oceans are in the North Pacific (3.2 Pg C) and the Indian Ocean (3 Pg C). If current rates of GHG emissions are not mitigated, oceans will be vastly different places by the mid-to-late 21st century (Gattuso *et al.*, 2015).

Ocean acidification negatively affects marine organisms and function, which in turn feedback to climate change. Acidification hinders the ability of calcifying organisms to build and maintain their calcium carbonate skeletons and shells, along with creating changes in other fundamental metabolic processes. Acidification also leads to increased phytoplankton production of dimethyl sulfide (DMS) (Gypens & Borges, 2014; Six *et al.*, 2013), which contributes to warming of the Earth's temperature due to a reduction in the reflection of solar radiation. Coral bleaching may also result from ocean acidification, although complex impacts upon the multiple trophic layers are hard to evaluate and predict (Hattich *et al.*, 2017; Kroeker *et al.*, 2010).

Impacts of increasing CO_2 upon the total Net Primary Production of marine systems and, thus, decreasing carbonate concentrations in the oceans and the atmosphere remain largely unknown. A global analysis reports that ~97% of reef areas exhibited warming trends, from 1985 to 2012. Coral bleaching incidents over the last two decades have been more frequent and more severe (Heron *et al.*, 2016). Summarizing, ocean acidification has been affecting fundamental physiological and ecological processes of organisms (Hoegh-Guldberg & Bruno, 2010; Pörtner *et al.*, 2014), leading to changes in the structure of marine ecosystems that underpin risks and vulnerabilities to food and income security (Hoegh-Guldberg *et al.*, 2017). Thus, the impacts of ocean acidification have a direct consequence for societies, including changes in national economies (Busch *et al.*, 2015; Robinson *et al.*, 2010).

2.1.18 PAST PATHWAYS: INCREASING CONNECTIVITY AND FEEDBACKS

Over 50 years, societies and nature have dramatically changed due to many complex interactions among the indirect drivers, among the direct drivers, and between the indirect and direct drivers. With a variety of impacts on nature, and nature's contribution to people, these interactions shape well-being for societies, and its evolution, including through governance motivations and choices.

As a result of increasing global connections, local impacts on nature and people are influenced by interactions at long distances, in some cases with significant time lags and with cumulative effects. The social-ecological changes from these accumulating interactions, from local to global levels, can occur in highly unpredictable ways due to varied conditions characteristic of complex systems, including: nonlinear processes underlying the outcomes; interdependence between distant places; changes with cascading effects; and both positive and negative feedback loops that can exacerbate or reduce the impact of changes on nature and people. All of this greatly affects future trajectories.

Below, we consider a few of the interactions and iterations that have such influences, starting with an illustration of varied correlations among indirect and direct drivers. With variations, by context, each indirect driver that we described can have both immediate and more distant causal impacts upon any number of actions that directly affect nature and, thereby, influences upon direct drivers.

2.1.18.1 Illustrating interconnections

Complex interactions and resulting interconnections between indirect and direct drivers may be partially summarized using statistical tools **(Figure 2.1.17)**. This does not sort out causal links involved, yet it does raise various questions about exactly how these specific correlations have come about.

The direct drivers – land/seascape change, resource extraction, pollution, invasive alien species (climate change was not included as it operates at very different spatial and temporal scales) – strongly correlate with multiple indirect drivers, in terms of the current levels for the indicators measured for each of the different countries **(Figure 2.1.17a)**. In particular, direct drivers correlate with total population, which also correlates with changes in nature (Biodiversity Intactness Index) and environmental footprint. Economic and lifestyle drivers (e.g., gross domestic product per capita, and domestic material consumption per capita) are also correlated with most of the direct drivers, nature and footprint indicators. Functioning institutions and governance (e.g., protection of key biodiversity areas, the absence of conflict) are correlated with some indicators of direct drivers, nature and footprint, though the processes involved are complex and cannot easily be identified from these correlations. Differences across IPBES regions are suggested for some direct drivers.

Looking at country variations in rates of change (1990–2010, **Figure 2.1.17b**), instead of levels variations, again the direct drivers were quite correlated with demographic, economic and lifestyle drivers, confirming the above observed patterns, and additional suggestive correlations were also found. Rates of change in urban populations were correlated with land-use changes, highlighting the indirect effects of urbanization. Human migration was correlated with increases in alien species, highlighting the roles of increased movements of people and goods on these non-native species. In addition, merchandise-export values were correlated with amounts of resources extracted, confirming paramount roles of trade in extraction of living and nonliving materials from nature. These broad patterns support more detailed assertions above and pose future research questions.

Related research is growing. Social–ecological literature has seen an exponential development in the last 15 years **(Figure 2.1.18)**, with a great deal of research on some actions (e.g., agriculture) with direct impacts on nature, plus how they link to climate change, land/sea-use change and economic and governance drivers. While such a map also cannot communicate causal links, as it does not reflect the content of the analyzed papers but rather the frequency of occurrence of terms linked to any of the indirect and direct drivers, it highlights research gaps. For instance, less was found on invasive and alien species, values, or trade-offs and inequalities.

2.1.18.2 Evolving economic and environmental interactions

2.1.18.2.1 Growing globalization

The world is ever more global, leading the environmental footprints of consuming nations to be spread ever farther from where the consumption occurs. Networks across continents, including flows of people, information, ideas, capital and goods, have been growing in the last decades at similar rates for all countries, while being clearly higher for the high income countries **(Figure 2.1.4)**. As a result, the footprint of nations is also growing globally, i.e., fractions of the total land use change, due to consumption, that occurred outside country boundaries have increased **(Figure 2.1.19)**. While high income countries were exporting a large fraction of their footprint even before 1990, even the poorest countries now have a large fraction of their footprints beyond their boundaries.

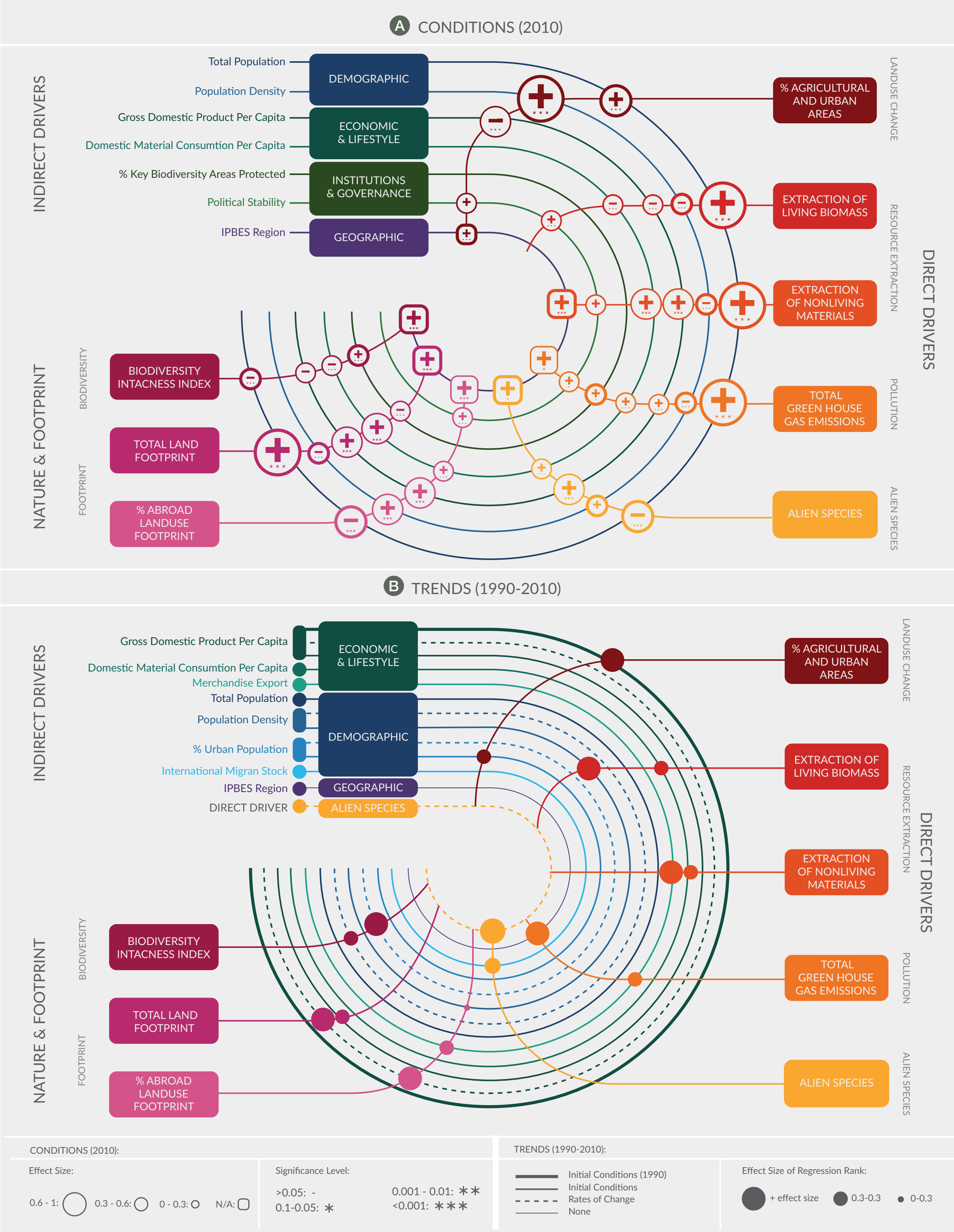


Figure 2 1 17 **Correlations between indirect drivers and direct drivers, as well as indicators of nature and footprint.**

A Correlations between current conditions of countries, (2010). B Correlations between trends of change in country values for 1990-2010. Multiple regression analysis was used as a way of summarizing correlations for current conditions, while regression trees were used for the correlations of the trends. Data used for correlations are by country. Corresponding average trends for development level categories are shown in Figures 2.1.4 and 2.1.12.

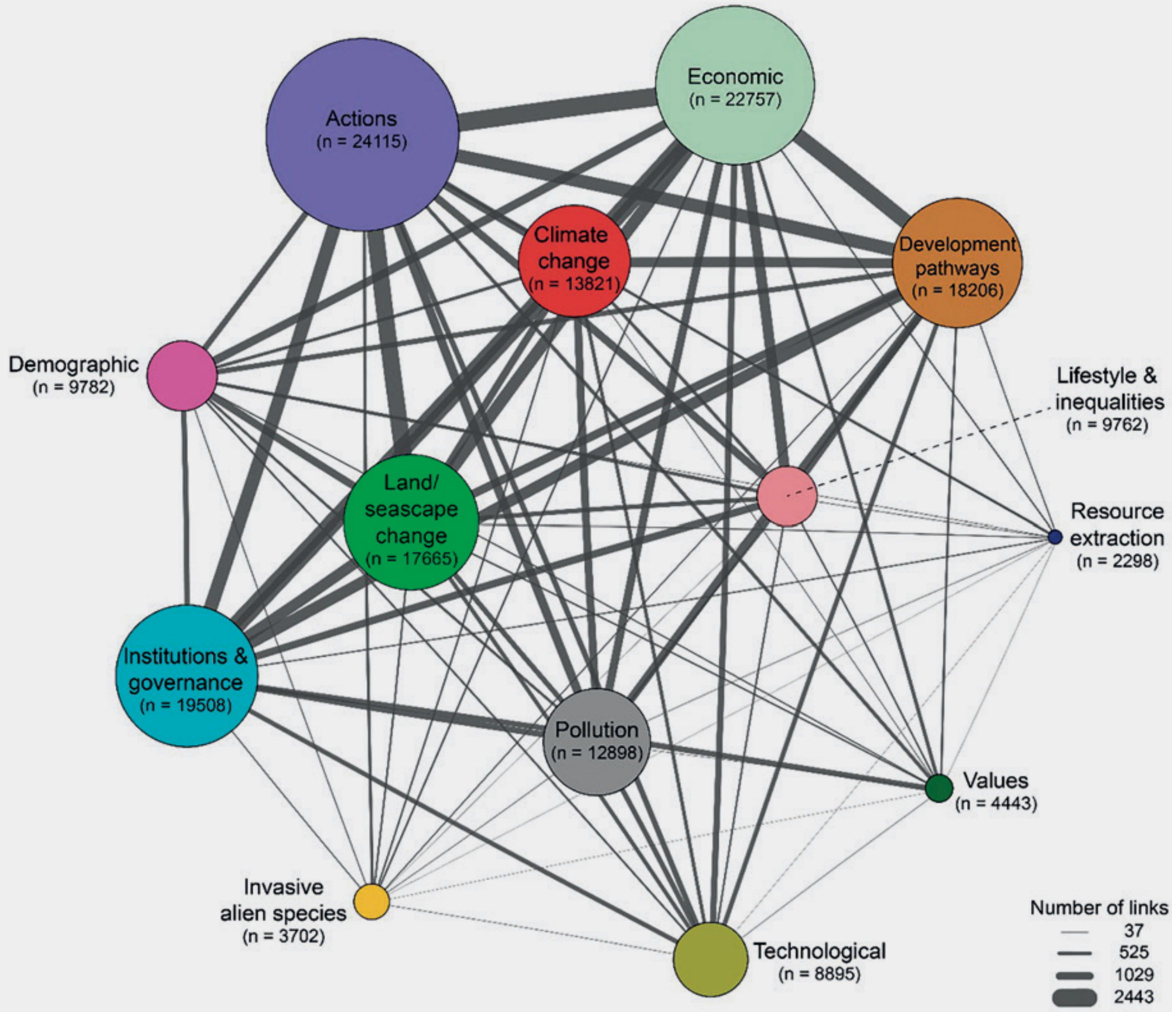


Figure 2 1 18 **Current state of knowledge on interactions among drivers from a systematic literature review.**

The number of papers that address each of the topics (circles) and that address two of them of (lines) are depicted. The literature surveyed was identified using keywords extracted from the Second Order Draft of this chapter, and using the bibliometrix R package, following Mazor *et al.* (2018) Sources: www.webofknowledge.com; www.bibliometrix.org.

2.1.18.2.2 Spreading spillovers

Spillovers from responses to environmental policies – even across borders – can undermine net impacts of governance efforts (see, for example, the case of palm oil, within **Box 2.1.4** below). Understanding and taking into account spillovers is important for evaluations, and for planning. Conservation efforts have expanded: legal limits, including protected areas and other restrictions; as well as positive incentives intended to discourage the degradation of nature (Chape *et al.*, 2005; Jenkins & Joppa, 2009), such as many programs using payments as compensation for protecting and restoring ecosystems (Albers & Grinspoon, 1997; Chen *et al.*, 2009; Daily & Matson, 2008; Uphoff & Langholz, 1998). Yet spillovers from these efforts, nearby or distant, are far from being understood and seldom taken into account (Meyfroidt *et al.*, 2018).

Responses to governance efforts across space and over time can hurt or help policies' objectives – environmental and economic. PAs, for instance, might not change land-use but just displace it (Hansen & DeFries, 2007), raising deforestation elsewhere (Robalino *et al.*, 2017 for local context and heterogeneous impact) while potentially also lowering local wages (Robalino, 2007). Yet context matters: with tourism, wages may rise (Robalino & Villalobos, 2015); and in cases, PAs lower deforestation nearby (Herrera Garcia, 2015) – including by dissuading local investments in economic development (Herrera Garcia, 2015). That

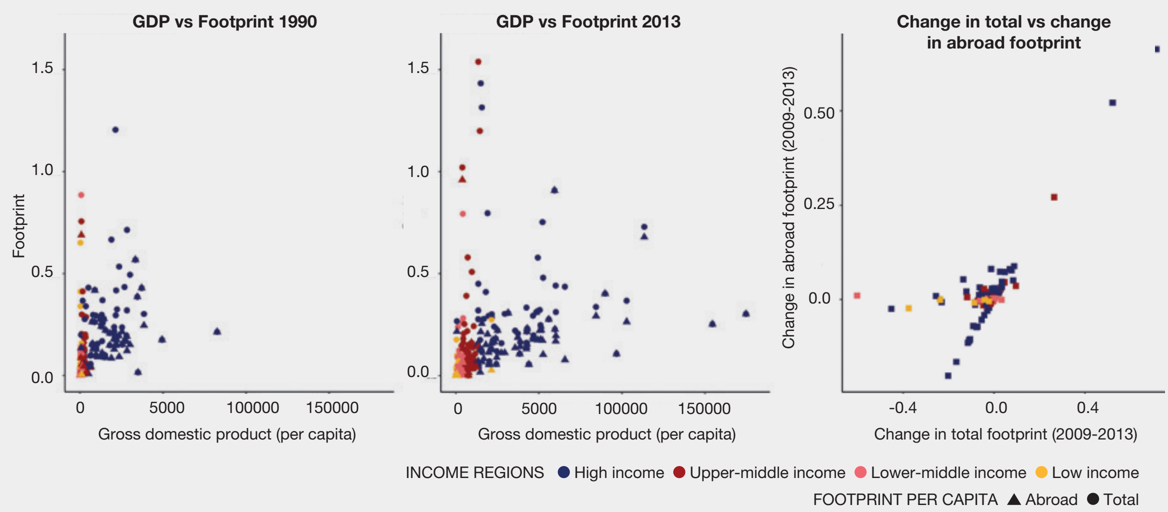


Figure 2 1 19 **Increasing total footprint of nations and exports of footprint: 1990-2013.**

Data shown is the footprint of individual countries, which is the sum of all land uses that occurs around the world to ultimately serve that specific nation's consumption. This land use footprint usually has a portion that occurs within the nation's own border (domestic), and a portion that occurs in within the borders of other countries (triangles), and the sum of these two components form the total footprint (circles). Countries are colored using World Bank's income categories. (Source: own calculations using Eora database, https://worldmrio.com/). The population and GDP data that were used for normalising the results were obtained from the Food and Agriculture Organization of the United Nations (FAO, 2016a; Wiedmann *et al.*, 2015).

may involve deforestation in other regions, if there exist broader spatial spillovers (DeFries *et al.*, 2010; Lambin & Meyfroidt, 2011; Rudel *et al.*, 2009b; Viña *et al.*, 2016; Zhu & Feng, 2003).

Understanding spillovers is essential to formulate policies. While there are studies of displacing land use (Lambin & Meyfroidt, 2011; Meyfroidt & Lambin, 2009; Pfaff & Walker, 2010) and deforestation (DeFries *et al.*, 2010; Liu *et al.*, 2012; Meyfroidt & Lambin, 2009; Verburg *et al.*, 2002; Wassenaar *et al.*, 2007), in policy formulation the consideration of human-nature interactions across spaces often is lacking. That could involve global scales, if prices rise in distant markets when one country lowers logging effort (Sedjo & Sohngen, 2000). Alternatively, it could be local, e.g., reduced motivations to conserve, for those who conserved voluntarily, if external interventions are perceived as a public overreach (Cardenas *et al.*, 2000).

Different spillover mechanisms yield different outcomes (Pfaff & Robalino, 2017). If PES for afforestation leads neighbors to learn that afforestation raises private profits, then others might start such practices in other locations – while those now receiving PES may continue practices after PES (Pagiola *et al.*, 2016 for Latin America). Such spatial and temporal spillovers benefit nature. Another potential spillover mechanism is that private or public conservation actions change the relative net benefits of conservation nearby. While Robalino & Pfaff (2012) find deforestation yields more private deforestation by neighbors, with tourism this can imply that conservation of nature yields neighboring conservation via local incentives to keep forest (Robalino *et al.*, 2017).

Moving to natural resources, many middle income countries possess stocks of oil and for some non-OECD high income countries, fossil fuels constitute a large share of their wealth. In such settings, discoveries can have spillovers through local incomes (Lange *et al.*, 2018b, p. 98) and prices. They can also bring 'the resource curse' (Barma *et al.*, 2012; van der Ploeg, 2011): although some resource-rich countries benefit from their natural wealth, in other countries it has been associated with bad macroeconomic performance and growing inequality among its citizens, with negative effects on other sectors of the economy due to concentrated growth. Further, as fossil fuels are nonrenewable, their extraction has effects upon the future.

Spillovers also imply gains from integration in the planning of development and conservation, for instance as related to transport investments. Consider a leading development policy, roads, and a leading conservation policy, protected areas. Roads increase profits in agriculture and, thereby, pressures for deforestation. That raises the impacts from well-implemented PAs (Pfaff *et al.*, 2016, 2009). Successful protection, in which PAs block the pressures, can in turn have positive spillovers through both agencies' interactions and private responses, as strong PA signals may lower expectations about economic prospects within any region. That has yielded reduced roads investments and in-migration (Herrera Garcia, 2015). Optimal policies could

Box 2 1 4 Palm oil illustrates multiple forms of interaction across national borders.

Palm oil production doubled in 2006-2016 to a global economic value of USD 65.7 billion in 2015. Demands in food (frying and cooking oils, baking fats, margarines, animal feed, confectionery filling, coffee whiteners, ice creams), oleo-chemicals (soaps, detergents, greases, lubricants and candle), fatty acids (to produce pharmaceuticals, water-treatment products and bactericides), and energy (biodiesel) fueled this increase, all encouraged by international capital (Borras Jr *et al.*, 2016) as well as the World Bank (Deininger *et al.*, 2011) and UNEP (Segura-Moran, 2011). States involved envision jobs and revenues to help mitigate high unemployment and to help supplement declining revenues, given falling commodity prices.

About 80% of production is in Indonesia and Malaysia – with the rest across Latin America and West Africa, e.g., growing in Cameroon (Hoyle & Levang, 2012) and Gabon (FAO, 2016a) – and consumption is highest in India, Indonesia, EU, China, Pakistan, Nigeria, Thailand, Bangladesh and USA. This generates tropical deforestation (Borras Jr *et al.*, 2011; Gibbs *et al.*, 2010), reduces soil fertility, raises water and air pollution (through fires) and biodiversity loss, pollutes with pesticides, and blocks communities from soil and water for livelihoods (Edwards *et al.*, 2010; Koh *et al.*, 2011; Temper *et al.*, 2015), while increasing human infections and premature deaths (Burrows, 2016; Fornace *et al.*, 2016).

In response to this, the EU voted to ban palm oil-based biofuels by 2021, while the Roundtable for Sustainable Palm Oil (RSPO) platform of principles, criteria, indicators and certification is followed voluntarily in Indonesia and Malaysia. RSPO has certified ~12 million metric tons (19% of output) with members in 91 countries and Indonesia proposed a Peatland Restoration Agency for 2 million ha, froze concessions, and started to work closely with large consumers.

Yet major plantation companies are shifting investments to Africa, where local values, nutrition, culture and markets in Congo Basin countries are disrupted as doubled prices fuel investment in medium-sized (5-50 ha) plantations in forested areas (Yemefack *et al.*, 2005). This growth has been linked to 'land grabbing' – both there and in the Guinea forest ecosystem, where several land acquisition deals by multinationals are reported (see www.landmatrix.org).

Consciously managing for multiple objectives, is important. One option is further agroecology. Agroforestry has potential for increasing productivity (and profit) and maintaining or enhancing ecosystem services. This requires multiple forms of support, including monetary incentives, technical training and other investment (Minang, 2018) to enhance the ability to manage land.

build from such non-cooperative interactions to pursue the coordination of roads and protection.

Similarly, concessions are a leading development policy in forests, awarding extraction rights. That alone can create incentives for private firms to defend forest assets from illegal invasions. Further, such a strong defense of rights may be a necessary condition for adding conservation influences of global consumer preferences as expressed through certifications (Rico *et al.*, 2017). Thus, further coordination across agencies could optimally locate concessions and protections. Protection also interacts with investment in hydropower, which has led to eliminations of PAs ('PADDD') but could be better coordinated to achieve multiple objectives (Tesfaw *et al.*, 2018).

2.1.18.2.3 Causing conflicts

Social instability is at the heart of environmental, social, economic or geopolitical threats (World Economic Forum, 2017, 2018) (see Figures S31–33). More than 2,500 conflicts over fossil fuels, water, food and land are currently occurring across the planet (including at least 1,000 environmental activists and journalists killed between 2002 and 2013. A report by the NGO Global Witness argues that 913 citizens were killed in their attempt to protect the environment between 2002 and 2013; and that the rate of such killing has been increasing (Global Witness, 2014).

While violent conflict may be decreasing (Lacina & Gleditsch, 2005), conflicts that destabilize social systems can have adverse environmental impacts, which in turn may cause or affect conflicts. Resource scarcities and/or unequal appropriations have triggered conflicts over fossil fuels, water, food, and land. Those conflicts undermine governance, in turn generating further shifts in threats to ecosystems in a harmful social-ecosystem feedback loop.

Links between resource scarcity and conflicts are not clearly established (Bernauer *et al.*, 2012; Koubi *et al.*, 2013), but clear examples, such as the role played by water scarcity in triggering violence in Syria, are available today. Water scarcity is exacerbated by contamination of local sources, the appropriation of water by agriculture, changes within land rights, food insecurity, unemployment, and political instability (Gleick, 2014). Civil conflicts in areas where valuable natural resources are found have tended to last longer, as the access to natural resources creates an economic incentive for armed groups (Lujala, 2010). The control of natural resources (timber, gems or oil) and the revenues from resources finance and motivate conflicts (Le Billon, 2001).

Disputes over use rights relevant for nature can trigger violence and destruction, particularly with weak governance (Brown & Keating, 2015). Violent conflict further disrupts institutions, causing insecurities and distrust (Miteva *et al.*, 2017). For centuries, resources have been linked to warfare

(Feldt, 2007). Matthew *et al.* (2009) suggest that 40–60% of civil wars in the past 60 years were triggered, funded or sustained by natural resources. Renner (2002) highlights that legal or illegal resource exploitation helped trigger, exacerbate or finance ongoing violent conflicts about the control of sites rich in valuable commodities or the points they pass through going to markets. Schaffartzik *et al.* (2016)) document that growing metals demand has generated incentives for countries to seek revenue through exploiting natural resources and exporting primary commodities, with the expansion of extraction frontiers generating conflicts. Billions of dollars can then go to unscrupulous actors.

Controlling natural resources is part of state-based and civil conflicts and an element within the repression of riots and even assassination of activists (Global Witness, 2014). Food riots also rise if food prices rise from physical or constructed scarcities (Lagi *et al.*, 2011). Such violence – including assassinations – can occur if communities are pushed off their lands or threatened by the degradation of their natural resources (Schoenberger & Beban, 2018). Violence might also be used to discourage resistance to large-scale degradation (Blake & Barney, 2018). More generally, conflict can be one symptom of an unequal distribution (Downey *et al.*, 2010) and can affect conservation as more untouched ecosystems harbor groups targeted by military operations (DeWeerdt, 2008). Looking out over time, armed conflict can lead to the withdrawal of financial aid, which is rarely reinstated after a conflict (Glew & Hudson, 2007).

In Indonesia ~20 million people have been affected by forest conflicts (Dhiaulhaq *et al.*, 2015) and the Environmental Justice Organizations, Liabilities and Trade (or EJOLT, www.ejolt.org) documents almost 2000 active environmental conflicts (see **Figure 2.1.20**) – most related to land, minerals, water access and dams (Giordano *et al.*, 2005; Martinez-Alier *et al.*, 2016; Seter *et al.*, 2016) – while the Latin American Observatory of Mining Conflicts

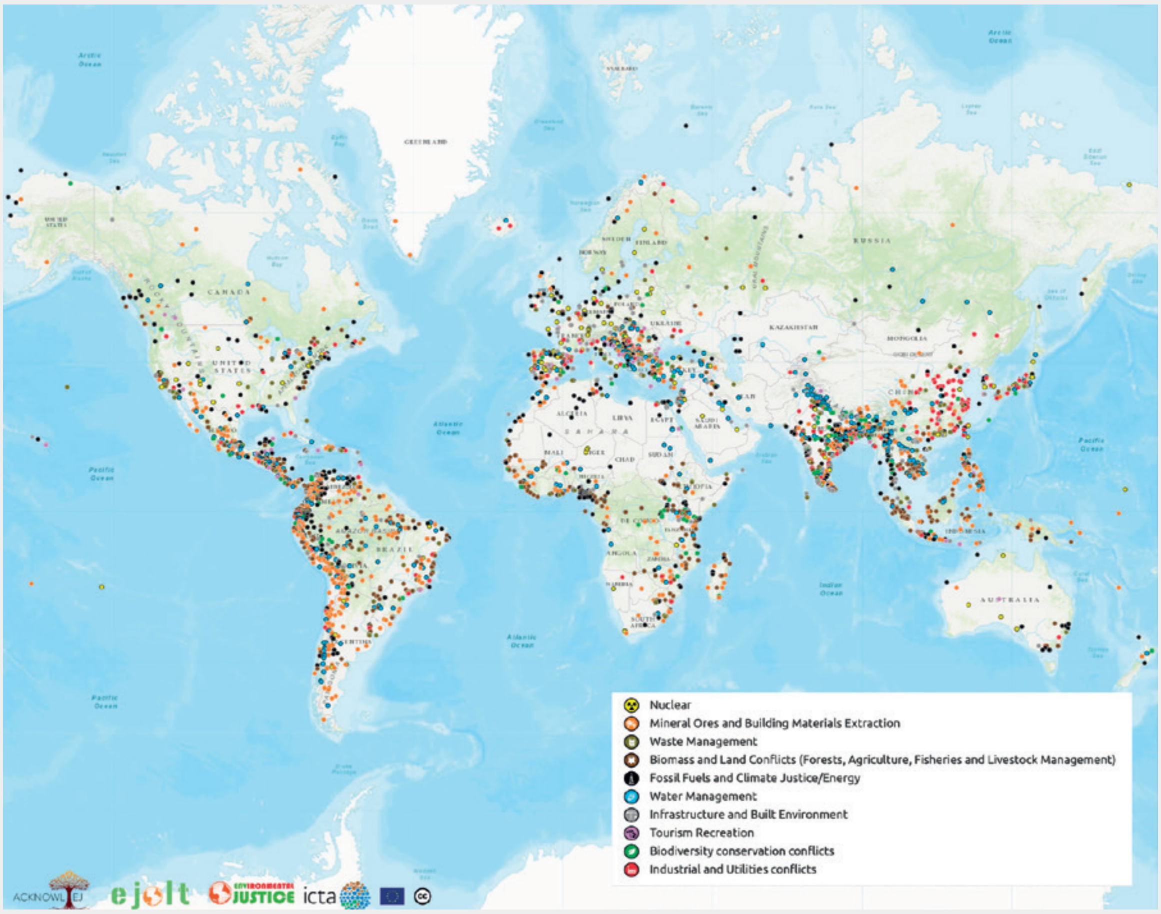


Figure 2 1 20 **Global map of environmental conflicts.**

The environmental justice atlas documents and catalogues social conflict around environmental issues, collecting the struggles of world communities to defend their land, air, water, forests and their livelihoods from damaging projects and extractive activities with heavy environmental and social impacts from around the world. Source: https://ejatlas.org/.

(www.conflictosmineros.net) notes over 150 active mining conflicts, most started in the 2000s after investments in mining in the 1990s (Urkidi & Walter, 2011; Walter, 2017). Butterman & Amey III (2005) suggest underlying international policy spillovers, i.e., that investment shifted due to environmental and labor regulations in Canada, and in the US, as well as due to political instabilities within the former Soviet Union, Asia and Africa. Some of the complex interactions involved in many such conflicts can be illustrated using the Nile Basin's example **(Box 2.1.5)**.

2.1.18.3 Evolving economic and environmental trade-offs

Across the globe, gains and burdens from nature are unequal for different sectors of society – and the trade-offs have evolved for all parties. For example, while a few firms are responsible for much of the fish harvesting around the globe (Österblom *et al.*, 2015), and a few countries are responsible for most of the carbon emissions (IPCC, 2013; Peters *et al.*, 2015), those who are most impacted by the consequences often are other groups that can include orders of magnitude more people with considerably less influence. In fisheries, FAO reports that 34 million people derive their livelihoods through fishing, while over 3 billion people get at least 15% of their protein intake from fish, especially in poor nations (FAO, 2014). Major ecological collapses have impacts upon international seafood market prices in markets (Smith *et al.*, 2017), but also upon the many small fish farmers and many consumers.

Environmental quality studies (Bowen *et al.*, 1995; Morello-Frosch *et al.*, 2001; Pastor *et al.*, 2002) find inequities can result from race and class barriers (e.g., **Box 2.1.3** above as well as **Box 2.1.6** above for including gender). In India, for instance, castes generate an important element of disproportionate pollution and other environmental stressors (Demaria, 2010; Parajuli, 1996). Tribal affiliation often counts in struggles against resource extraction processes, as in the case of Nigeria and other countries in which companies have shifted social and environmental costs of oil extraction onto Indigenous and poor local communities (Martinez-Alier *et al.*, 2014).

These inequalities have serious health consequences. A quarter of deaths and years of life lost are attributed to environmental degradation (Figure S31), with the highest fraction in low and middle income countries (WHO, 2016) given chemical or biological pollution of air, water and soil via agriculture, irrigation, and sanitation. Poor, rural communities are disproportionately affected (WRI, 2017). Negative effects of extreme events affect vulnerable communities in developing countries, who are least able to cope with the risks (Smit & Wandel, 2006), including of climate change (Mirza, 2003) and a likely multitude of primary and secondary effects (Adger, 2003).

Climate change, e.g., a 3°C warming with a 3% loss of GDP, will likely exacerbate inequalities (Mendelsohn *et al.*, 2000; Nordhaus & Boyer, 2000; Tol, 2002). Countries with higher initial temperatures, greater climate change levels, and lower levels of development, which often implies greater dependence on climate-sensitive sectors and in particular agriculture, are expected to bear the highest levels of impacts (Golden *et al.*, 2016, 2017; Marlier *et al.*, 2015; Myers *et al.*, 2014; Vittor *et al.*, 2006; Whitmee *et al.*, 2015).

More generally, losses of natural capital are unequally distributed across countries and regions (**Figure 2.1.21**, Lange *et al.*, 2018a). Further, these inequalities arise within countries as well, including along gender-based and race-based and income-based dimensions within developed countries.

Box 2 1 5 Nile basin's water allocation conflicts, with equity and efficiency considerations.

The Nile basin provides examples of conflicts concerning water allocation at the national scale, i.e., between nations, within an enormous region. This basin covers over 3 million km^2 with an annual discharge of 84 billion m^3 which supports over 200 million people within 10 countries: Burundi, Democratic Republic of Congo, Egypt, Ethiopia, Kenya, Rwanda, Tanzania, South Sudan, The Sudan and Uganda. About 86% of the water from the Blue Nile originates from Lake Tana, which is within Ethiopia. Yet downstream 97% of the water needs in Egypt are fulfilled by the Nile, setting up potential tensions concerning the management of agroecosystems upstream.

Thus, not surprisingly, the decision by Ethiopia to build the Grand Renaissance Dam, which is now under construction, has created conflict with Egypt. Egypt says that the dam will reduce the flows to the lower Nile and that it will lose almost 3 billion m^3 to evaporation. Ethiopia responds that Egypt is losing 12 billion m^3 via the Aswan Dam, which is in Egypt (Di Nunzio, 2013).

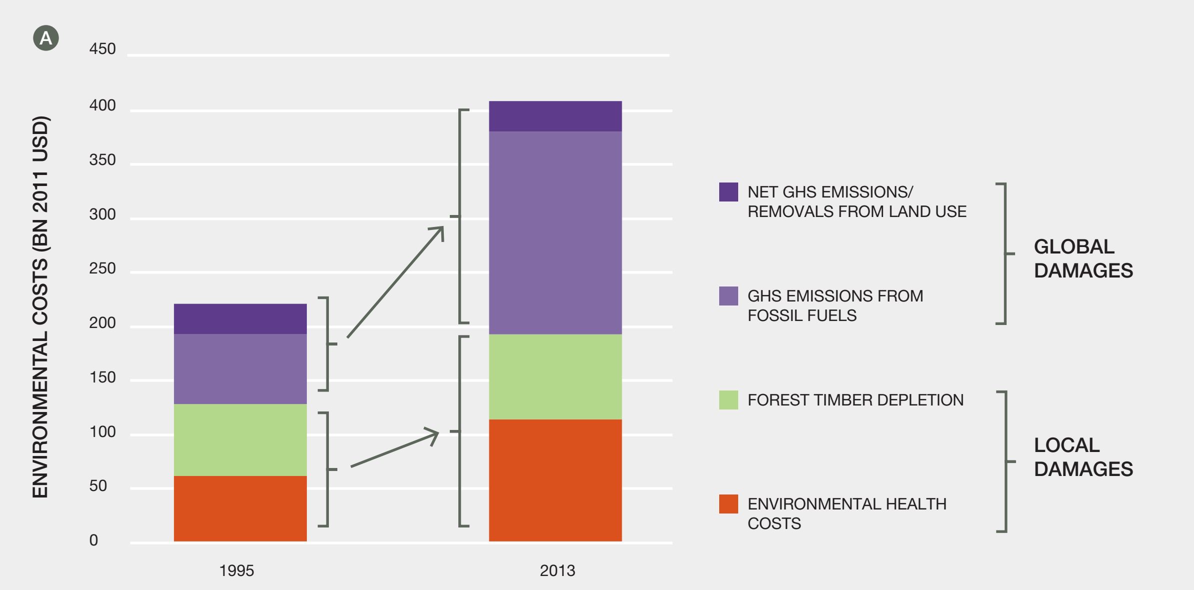
The region is rising in population and is modifying agroecosystems to meet needs for food, fuel and fiber. Given rising demand and its impacts on biodiversity, water resources and ecosystems, in order to work out rights structures for both sustainable management and fair utilization the Nile Basin Initiative was established in 1999 with support from each of the ten related countries. Only coordination can ensure sustainability for so many people and ecosystems (Swain, 2002).

Box 2 1 6 Scale, gender, and ecosystem-based differences for trade-offs within fisheries.

At the turn of the century, industrial fisheries and small-scale fisheries (SSFs) (Vásquez-León & McGuire, 1993) disagreed about inequitable relations including competition (Lawson, 1977; Vásquez-León & McGuire, 1993), preferential treatment by the state of the industrial fisheries (Panayotou, 1980; Pauly, 1997), access to specific fishing grounds (Begossi, 1995) and gear (Sunderlin & Gorospe, 1997). Conflict arose between fisheries, conservation and tourism (White & Palaganas, 1991) as well. SSFs were seen at odds with nonconsumptive uses of marine resources (Basurto *et al.*, 2017; Newman *et al.*, 2018). Agencies adopting mandates of conservation and protection were seen as against SSFs (Breton *et al.*, 1996). The conflicts were especially salient around endangered species and charismatic megafauna (Kalland, 1993). Jobs were said to be replaced in tourism and 'green' services yet fishers were skeptical (Young, 1999).

The literature has relied on technology to differentiate SSFs, often with unintended consequences (Basurto *et al.*, 2017). Definitions stress technical capacities, e.g., boat lengths, horsepower, and gear (Chuenpagdee *et al.*, 2006; FAO, 2009c; Smith *et al.*, 2017), excluding some SSF activities. To start, catching fish at sea is a predominately male activity (FAO, 2016b), while women play large roles in shore-side SSF efforts such as procuring ice, bait, food and fuel, accounting, managing, financing, fish processing, trading and marketing (Harper *et al.*, 2013; Thorpe *et al.*, 2014). These are labeled as supporting activities (Gereva & Vuki, 2010; Kleiber *et al.*, 2015; Tindall & Holvoet, 2008) or, when women are fishers (Béné *et al.*, 2009) in intertidal and shallow zones it is labeled as collection and gleaning and gathering (FAO, 2015a; Pálsson, 1989; Worldfish Center, 2010). Gender bias has implications for science, management, and the access to key resources. Most data measure only men's effort at sea from interviewing men (Kleiber *et al.*, 2015; Smith *et al.*, 2017), underestimating aggregate SSF economic contributions. Also, comprehensive ecosystem management – including of zones important for juvenile fish (e.g., seagrass beds, mangroves) – requires understanding all SSF practices (Kleiber *et al.*, 2015). Further, as women are often excluded from representing their concerns in the dominant fisheries governance processes (FAO, 2006; Okali & Holvoet, 2007; Porter, 2006), they are more vulnerable to tenure insecurity, marginalization and poverty (Harper *et al.*, 2013). Alternative SSF definitions are emerging. FAO's Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (SSF-Guidelines) defines SSFs with all activities along the relevant value chains – e.g., "pre-harvest, harvest and post-harvest" by men or by women (FAO, 2015a). Its implementation will shift SSF futures.

Challenges differ for inland fisheries facing agricultural runoff, introduced exotic species, and human uses (Youn *et al.*, 2014) such as hydropower, flood control, and irrigation (Baran *et al.*, 2007). In many developed countries, commercial fisheries have diminished in favor of alternative uses of freshwater, including recreational fishing, and scale again matters. Inland fisheries often feature small-scale harvesting (Bartley *et al.*, 2015) but large-scale, commercialized fisheries have large vessels and highly mechanized gear – e.g., the kilka fishery in the Caspian Sea (FAO, 1999), mechanized operations on lakes in Finland and the United States or estuaries in the Brazilian Amazon (Carolsfield, 2003; GLMRIS, 2012; Salmi & Sipponen, 2017) and long bag nets in the Tonle Sap Great Lake in Cambodia (Lamberts, 2001). Such operations may be more easily monitored and governed than dispersed fishers. Trade-offs between revenues and food security (Abila, 2003) arise for high-value exports (Lake Victoria Nile perch generated 250 million USD in 2012 (IOC, 2015)), given vulnerable stocks (Ermolin & Svolkinas, 2016).



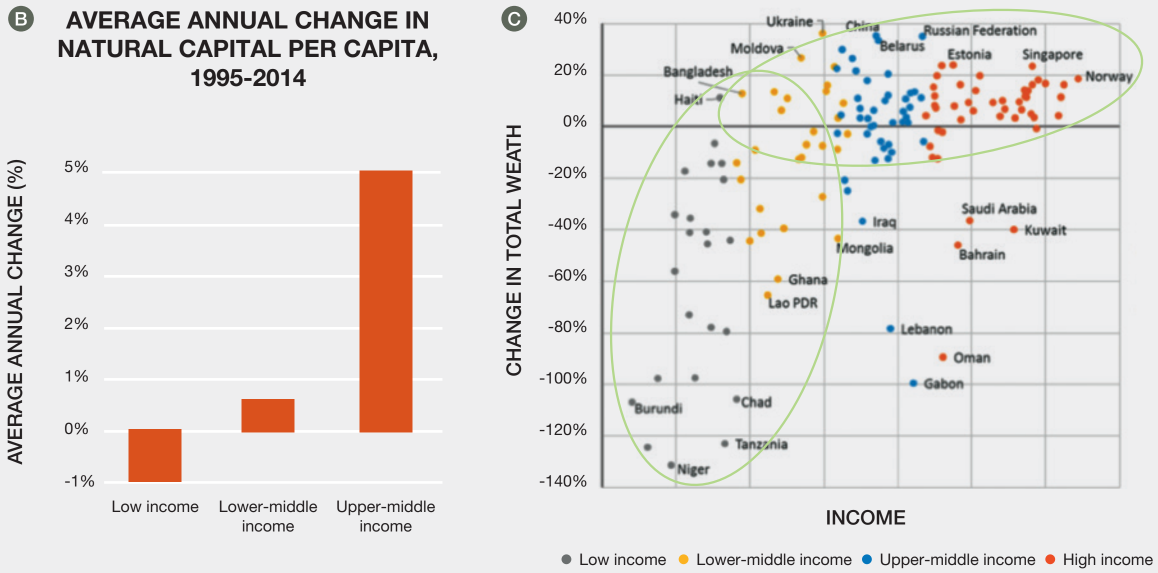


Figure 2 1 21 **Unequal gains and losses from changes in nature 1995-2014.**

A Increase in local and global environmental and societal costs, both global and local in billions of 2011 USD. B Average annual change in natural capital per capita for countries with contrasting levels of income, in average annual change in per cent. C Average annual changes in total wealth relative to changes in income per country; colors are used to distinguish countries of different income levels, using World Bank categories. Source: Lange *et al.* (2018a), see The Hidden Dimensions of Poverty (https://slideplayer.com/slide/11877123/).

2.1.18.4 Feedback loops and natural-social trajectories

Growing literature on social-ecological dynamics has largely explored actions (e.g. agriculture, fisheries, forestry, mining sectors) and the economic (e.g. trade, income, economic composition), and governance indirect drivers – alongside some work on positive and negative feedback loops, in a complex-systems sense of exacerbating or diminishing the forces going in a given direction.

Here we consider interactions and feedbacks that lead toward more or less desirable natural and social outcomes. This brings us full circle back to the trajectories highlighted in the Introduction.

The dynamics underlying development pathways described in the Introduction include feedback. Thus, as noted, initial conditions for the many consequential indirect drivers can lead to actions, aggregated impacts, changes in nature, shifts in NCP abundance or scarcity and, thus, changes in indirect drivers including values, prices, governance institutions, and more. Such feedback loops can push towards balancing or, instead, towards more extreme outcomes, both natural and social.

Below, we consider some relevant pieces of such feedback loops, although much remains to be studied concerning loops relevant for nature. First, we consider changes in trajectories, including abrupt changes, with feedback towards environmental degradation. Second, as part of responses to such trends, we consider individuals' and groups' feedback to governance responses. Finally, we scale upwards for possible feedback loops that lead in more desirable directions for nature.

2.1.18.4.1 Interactions, abrupt changes, and linked negative trends

Dramatic changes in nature can result from feedback that emerges from complex interactions between indirect and direct drivers – which can exacerbate the rates of degradation of nature. Regime shifts, for instance, are large, abrupt and persistent changes in the function and structure of systems (Scheffer & Carpenter, 2003). They occur at different spatial and temporal scales in marine and terrestrial systems (Rocha *et al.*, 2015). A 'regime shifts data base' documents over 30 different types of these abrupt changes (Figure S34) with >300 case studies based on a literature review of over 1000 scientific papers (Biggs *et al.*, 2015).

Regime shifts are increasingly observed. While they can occur naturally, under current trends of environmental forcing they might be more frequent and severe than observed. Climate change and food production have large forcing impacts (DeClerck *et al.*, 2016; Foley *et al.*, 2005;

Gordon *et al.*, 2008; Rocha *et al.*, 2015) and such shifts are expected to occur widely, but particularly in the Arctic (AMAP, 2012; Ford *et al.*, 2015; IPCC, 2013; Peterson & Rocha, 2016) where climate impact is felt relatively quickly. Another example of a regime shift is hypoxia in coastal systems, where oxygen levels fall low enough to produce 'dead zones' whose frequency and extent has risen across recent decades (Diaz & Rosenberg, 2008) and are more pronounced in the Northern Hemisphere, given common use of fertilizers. In the US only, more than 500 such 'lifeless' zones have been reported (Figure S35).

Shifts within the Arctic region have led communities to self-organize and to promote adaptive capacity (Huitric *et al.*, 2016), yet Arctic communities are, on their own, of course often limited in influencing the drivers of the regime shifts (Peterson & Rocha, 2016). Policies to manage many of the shifts that affect those communities require coordinated actions over scales which address the diversity of drivers (Rocha *et al.*, 2014).

Feedbacks between health and nature can arise when health and nature's status affect each other. The uses of antibiotics by humans (including over-use or mis-uses), for example, build resistance in nature (Laxminarayan *et al.*, 2013), thus contributing to negative impacts of nature on people. Chronic and infectious diseases and epidemic outbreaks shape household uses of nature, driving land management and dictating investments and policy. An E. coli outbreak changed landscape management in the US, for instance, as farmers eliminated hedgerows to avoid contamination by small mammal feces (Martin, 2006). In East Africa, poor health contributes to destructive and illegal fishing practices (Fiorella *et al.*, 2017), while sustainable agricultural practice is more common with improved access to anti-retroviral therapy (Damon *et al.*, 2015). Illnesses shift management of landscapes, e.g., malaria risk shapes tropical wetlands management (Malan *et al.*, 2009) while Zika control efforts include widespread insecticide use in the Americas and Pacific region (Blinder, 2016; Petersen *et al.*, 2016). Illness burdens – staggering globally and in sub-Saharan Africa and South Asia in particular – have implications for allocating budgets toward concerns deemed more immediate than nature. These kinds of interactions allow for unfortunate and linked trends in nature and human health.

2.1.18.4.2 Citizen feedback to governance

Well-informed citizens vote for representatives who share their views on the use of nature, in a democratic ideal. Yet, the fraction who vote has been well below 100%, globally. Voting may be irrational (Downs, 1957) and uninformed (Campbell *et al.*, 1960; Converse, 1964; Fiorina, 1981; Zaller, 1992), Studies find biases(Shogren & Taylor, 2008) and assess "nudges" around energy (Gillingham *et al.*, 2006; Sunstein & Reisch, 2014), including 'learning' via comparisons to neighbors (Allcott, 2011; Ayres *et al.*, 2013). In Ireland, real-time information affected behaviour (Gans *et al.*, 2013), although effects may decay without sustained information (Allcott & Rogers, 2014). 'Moral persuasion' (Ito *et al.*, 2018; Reiss & White, 2008) had effects only in the short-run, rising with income but lower for political conservatives (Costa & Kahn, 2013). Social identities matter (Bartels, 2002; Cassino & Lodge, 2007; Greene, 1999; Hillygus & Shields, 2014; Huddy, 2001; Kahneman & Tversky, 1979; Krosnick, 1991; Quattrone & Tversky, 1988). While values and identities may override (Kahan *et al.*, 2011; Layzer, 2006), so too do prior exposures and interactions (Brody *et al.*, 2008; Egan & Mullin, 2012). Framing around health (Myers *et al.*, 2012) and victims (Hart & Nisbet, 2012) can activate concerns and voting. Uncertain perceptions and a growing polarization and segmentation of media limits information (Hollander *et al.*, 2008).

Activists, firms, scientists and experts all inform both citizens and states (Keck & Sikkink, 1998), with influence via ideas and information, including from monitoring and connecting actors and setting agendas (Betsill & Corell, 2001; Wapner, 1995). Over time some NGOs have acquired roles in environmental regimes – nationally and internationally (Wapner, 1995). Some focus on facts: 'epistemic communities' (Sebenius, 1992) influence choice given uncertainties about social and physical processes (Adler & Haas, 1992) by developing knowledge or solutions, plus lobbying (Gough & Shackley, 2002). International learning can facilitate improved policies (Adler & Haas, 1992).

Free flow of information, civil liberties and regime receptiveness to citizen demands all suggest better environmental quality for democracies (Payne, 1995). Yet India – the largest democracy – faces severe environmental quality issues while Singapore ranks high alongside Norway and Sweden (EPI, 2018). Citizens can be aware of issues regardless of state-provided information, as they live with the problems (Arvin & Lew, 2011; O'Rourke, 2004; Winslow, 2005). Further, less democratic regimes do not restrict all information (King *et al.*, 2013 on censorship within China), even if any information that could galvanize collective action might be restricted. Participation modes for environmental actors have included protests in Vietnam and Myanmar to demand less degradation (Doyle & Simpson, 2006; O'Rourke, 2004). While that is not always effective, not all environmental participation is effective in democracies. Pavlinek & Pickles (2004) note the prioritization of the economy instead of environment in post-Soviet Central and Eastern Europe (CEE), yet Midlarsky (1998) sees "no uniform relationship between democracy and the environment" while Pellegrini and Gerlagh (2006) and Pellegrini (2011) suggest effects of democracy in decreasing degradation are overstated and that corruption could undermine all.

Leaders' incentives have mattered (Congleton, 1992; Ward *et al.*, 2014), e.g., private income gains from polluting and extracting (Deacon, 1999; McGuire & Olson, 1996; Olson, 1993). If the elites lose rents in stringent regulatory regimes, while the benefits of conservation are diffuse, leaders may not strengthen nature (Bernauer & Koubi, 2009; Cao & Ward, 2015). The time horizons matter too. Lasting institutions include legislatures (Gandhi, 2008; Gandhi & Przeworski, 2007; Svolik, 2012) and political parties (Brownlee, 2007), which can extend the temporal perspective.

In the 1970s, state policies were often varied command and control limits on pollution through output or technology requirements (Coglianese & Lazer, 2003). While relatively easy to implement, these have inefficiencies due to inflexibility (Jaffe *et al.*, 1995) and the distrust and adversarial legalism that often results. As Kagan (1991) describes, legal rules and adversarial procedures for resolving disputes often lead to costly winner-takes-all judicial battles with both cost and delays. This can result from a closed-door approach in which agencies ignore firm and local knowledge, lowering 'buy-in' (Beierle & Konisky, 2001; Coglianese & Lazer, 2003). This can create opportunities for 'capture' by interest groups (Oates & Portney, 2003) that have influence in traditional regulatory processes – often reflecting the power of concentrated production and finance. Recently, greater attention has been given to collaborative governance by public and private actors (Fiorino, 2006): "agencies directly engage non-state stakeholders in a collective decision-making process that is formal, consensus-oriented, and deliberative" (Ansell & Gash, 2008). Walker et al (2015) describe such approaches: first, the state informs and educates citizens via public meetings and notifications; second, regulating entities request public input on policies, as through comments, though technical complexity requires the agency to do more policy formulation; and third, more complete collaboration where agencies and private stakeholders equally construct new policies.

Water management provides some examples, from across the globe, of significant variation in such processes. In Singapore, a Public Utilities Board (PUB) manages electricity, gas and water supply plus legislation to address sewerage, effluents, drinking water quality and more (Luan, 2010). After focusing on construction and maintenance, it now also does 'demand management' to encourage citizens to conserve. India's National Water Policy is coordinated by the Ministry of Water Resources as a tool for planning and development of water resources. Adopted in 1987, this legislative pact was relaunched in 2012 to emphasize water as an 'economic good' and, thus, promotes efficient use and conservation. Beyond potable water access, a recent addition is flow in water channels to meet ecological needs. Canada also adopted a Federal Water Policy in 1987, noting intensive consultation with diverse stakeholder groups given two key objectives: improve the quality of the water resource; and advocate freshwater use in an efficient and equitable way, coherent with the social, economic and environmental needs of present and future generations.

2.1.18.4.3 Scaling up and extending positive responses

Multiple existing initiatives have both a positive potential and some potential to be scaled up for moderating negative impacts on nature and good quality of life, toward more sustainable futures. One compilation is the "Seeds of Good Anthropocenes" initiative[3] that aims to explore and articulate positive futures (Bennett *et al.*, 2016). Up to 500 initiatives which demonstrate elements of positive futures have been identified **(Figure 2.1.22)**, towards testing theories about how desirable transformative pathways can supported (Pereira *et al.*, 2018). They include social movements, ways of living or doing things, technologies and designs, and governance. For example, Yachay City of Knowledge is a "New City" under development in rural Ecuador, conceptualized to be a technological research and innovation hub containing research facilities, a working university, and bio-tech companies. "Tribal parks" are an example of Aboriginal people being recognized as co-managers of national parks in Canada[4]. The Foundation for Ecological Security is an Indian NGO which is working to reduce poverty by helping communities organize to restore their ecosystems while also enhancing their livelihoods in over 8,000 village institutions in 31 districts across 8 states, having already supported some form of restoration of over 1 million ha while training 350,000 people in both ecological restoration and management of village institutions[5].

Quite broadly, many voices have called for alternatives to current global development pathways (see also chapters 5 and 6). There are calls for 'degrowth', with changes in social and political priorities (Odum & Odum, 2006). Ecological sustainability and social justice are called out, e.g., "an equitable downscaling of production and consumption that increases human well-being and enhances ecological conditions at the local and global level" (Schneider *et al.*, 2010). Whether this will be widely embraced or scaled up as a goal remains to be seen.

Consumer-driven initiatives to demand sustainable land-use management and the restoration of degraded lands have arisen in recent decades (IPBES, 2018a). Companies have responded by committing to reduce impacts upon nature and the rights of local communities, including taking steps to, e.g., eliminate deforestation due to supply chains by

3. https://goodanthropocenes.net/
4. http://www.tribalparks.ca
5. http://fes.org.in

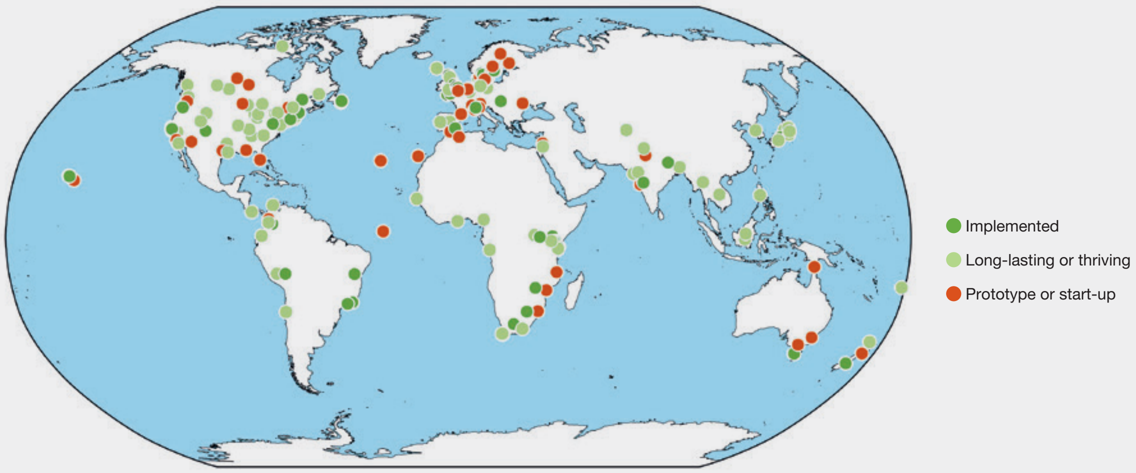


Figure 2 1 22 **Seeds of Good Anthropocenes.**

The Bright Spots team used an international participatory process to identify over 500 initiative globally, and gathered data on how they are established, grow, spread, or inspire positive change elsewhere.
Sources: Future Earth (2017), Bennett *et al.* (2016).

2020. State and civil-society groups have committed to restore hundreds of millions of hectares of degraded lands. Following all this, the finance sector is starting to make explicit commitments to reduce its environmental impacts.

Other alternatives to global development pathways have emphasized how nature's contributions are valued and currently marketed – versus how they could or should be. These have highlighted incentives and the potential from clear ownership and use rights, with private-market interactions that facilitate price feedbacks to address scarcities. For example, when an earthquake shuts down copper mines, the futures market quickly lowers expectations of supply, through higher prices, that in turn shifted any number of private plans, from computer wiring through kitchen redesign. Most generally, following signals of natural scarcities, relevant decisions have adjusted to help.

Industrial ecologists note that responses to environmental quality and natural resource scarcities have been considerably more complex, even if guided by a simple pursuit of profits. Paraphrasing Frosch & Gallopoulos (1989), the wastes from one industry can be the inputs for others, reducing the total usage of all raw materials as well as the generation of pollution into the environment. This has occurred in residences, too, with 'gray water' from apartments feeding urban roof gardens. While all of that requires coordination, in principle it is motivated by private costs or profits alone.

Limits on such useful feedback processes have included: information; rights; and transaction costs. Since the private payoffs from resource use and environmental degradation drive private choices, in many settings even commendable private responses have come up far short of social sensibility. The simple, obvious and pervasive reason for this is that private actors often have not taken into account how other people would lose (or gain) from those actors' choices concerning degradation. Sometimes actors did not know about effects on others, which suggests potential from initiatives such as efforts to communicate with relevant actors, e.g., via certifications of production processes. Yet often people simply have not in their daily decisions given equal attention to effects on others – even though, clearly, there exists both altruism and various private provisions of public goods. Thus, even if fully informed about effects on others, private actors were not bound to incur costs to benefit others, and often did not, raising questions about public roles concerning those affected.

When people affected by others' behaviours had the publicly defended right to clean air, or water, producers degrading others' environment and resources were forced to get consent and, at times, compensate the affected. That shifts private costs and benefits and, thus, plans. Given appropriate public frameworks, those signals of the need to adjust were stronger as scarcities in nature rose, shifting further the trade-offs for degrading production. Yet such frameworks often were lacking.

When rights were clear, and incentives aligned, actors gained in their own management decisions from information due to assessments – even by others. It appears as though larger fisheries, which tend to be more systematically assessed, are doing better in maintaining fish stocks, on average, than small, formally unassessed fisheries (Costello *et al.*, 2012). Even so, there can exist multiple stable points of equilibria within such fully informed social-ecological systems, given social and natural sources of feedback. Fishing effort responds often to the state of the fish stock, which is in turn affected by fishing-effort levels. If sustainability-oriented decision rules imply that the fishing effort falls as the scarcity of the fish rises, then they can stabilize stocks as can regulations informed by ecological and human response models (Yun *et al.*, 2017) **(Figure 2.1.23)**.

Notwithstanding the many types of past contributions to support nature, by many private actors, many outcomes in private contexts often have indicated a need for public responses to scarcities. Public actors with overarching mandates have not only set up appropriate frameworks to address trade-offs – leading to quantity and price policies – but also lowered solutions' transaction costs. For instance, states have required information, e.g., labeling with energy use for refrigeration or, more involved, certifications of legal sourcing for forest products, under which public rejections of illegally harvested timber

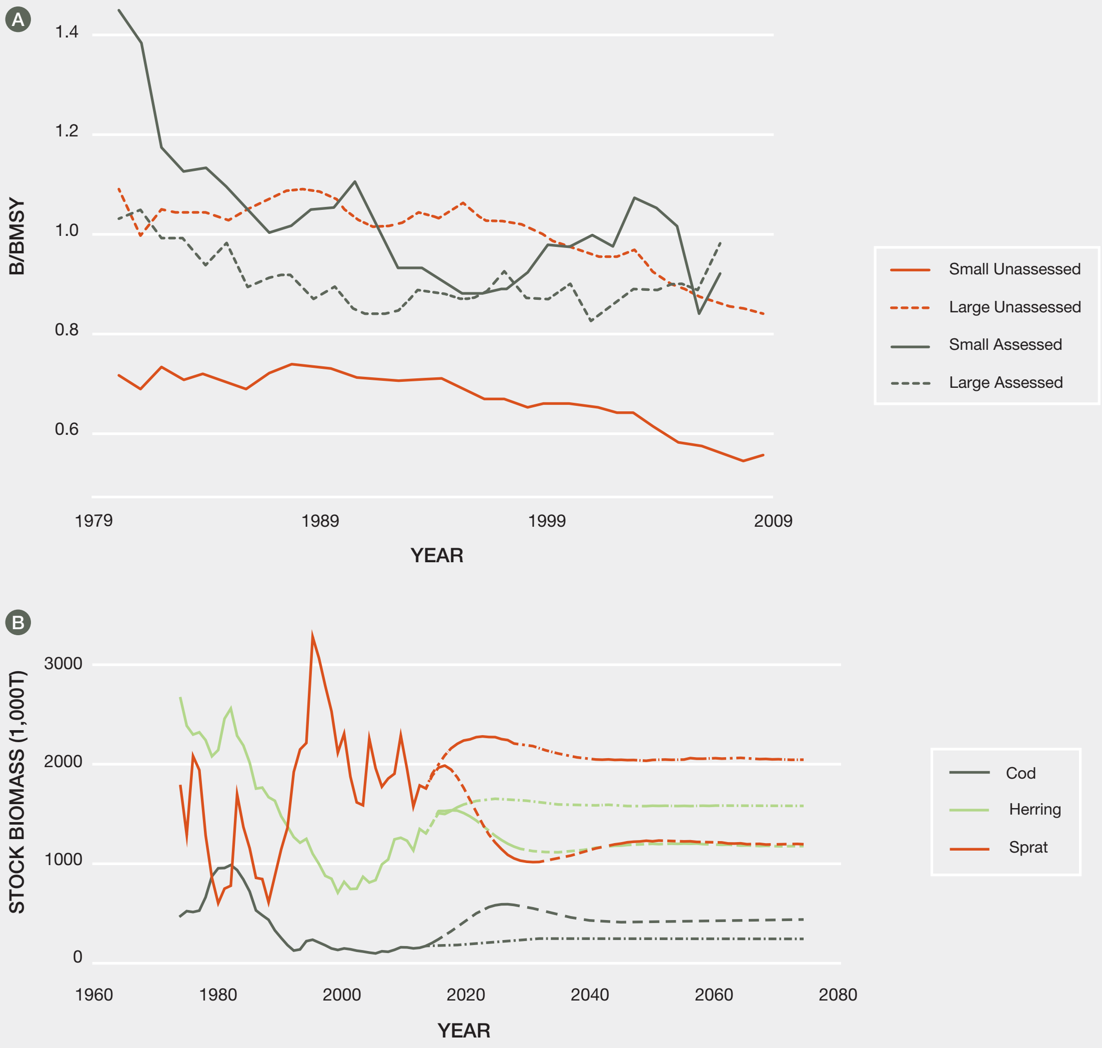


Figure 2 1 23 **Fisheries can show positive trends into the future when adequately managed and governed.**

Ⓐ The ratio of observed biomass to the biomass that would provide maximum sustainable yield (B/Bmsy) has stabilized for small and large fisheries that are being constantly monitored (assessed). Ⓑ Fisheries can stabilize at different equilibria level when managed for single-species (dashed lines), and under ecosystem-based management (dot-dash lines).
Sources: Costello et al. (2012), Yun *et al.* (2017).

have occurred (e.g., under the EU's FLEGT or the U.S. Lacey Act).

Further, many crucial incentives and empowerments of private actors involved the creation or the enforcement of some form of right, such as indigenous lands or smallholder land tenure or firms' concessions for timber harvesting or the right to clean air as implied by limitations on emissions. Like private choices, establishment of such limitations or rights has tended to respond to scarcity.

Stepping back, while in the past a large set of such institutions have generated social efficiency, as well as equity when attention has been given to that critical outcome as well, in practice there exist considerable institutional challenges. Just as private collective action to form institutions was not always successful – given multiple determinants of such coordination – public processes will not always effectively address environmental and resource scarcity. Some actors do not wish to do so. This suggests considerable attention is needed to environmental politics, alongside policy design.

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Chapter **2.2**

STATUS AND TRENDS – NATURE

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STATUS AND TRENDS – NATURE

EXECUTIVE SUMMARY

1 **Humanity is now a dominant influence on nature worldwide *(well established*) {2.2.5, 2.2.7}, with many impacts having accelerated rapidly in the 20th century *(well established)* {2.2.5.2}.** Humanity has influenced nature significantly since prehistory, both positively (e.g., development of agrobiodiversity) and negatively (e.g., extinction of megafauna and flightless island birds) *(well established)* {2.2.4, 2.2.5.1}; but nature – including species, their genes and populations, communities of interacting populations, ecological and evolutionary processes, and the landscapes and ecosystems in which they live – is now declining rapidly and many facets of nature have already been much reduced *(well established)* {2.2.5}, supporting suggestions that Earth has entered the Anthropocene.

2 **Much of nature has already been lost, and what remains is continuing to decline {2.2.5.2}**. Indicators of the extent and structural condition of ecosystems, of the composition of ecological communities, and of species populations overwhelmingly show net declines over recent decades; most of the exceptions are themselves symptoms of damage (e.g., the biomass of prey fish has increased, but this is because humanity has harvested most of the bigger fish that prey on them; and terrestrial vegetation biomass – though still only around half its natural baseline level – has increased slightly in recent decades, mainly because elevated CO_2 slightly increases photosynthesis) *(well established)* {2.2.5.2.1, 2.2.5.2.3, 2.2.5.2.4}. Some declines have slowed (e.g., the extent of forests is reducing less quickly than in the 1990s) and some have even been reversed (e.g., area of tree cover is increasing), but others are accelerating (e.g., most of the total extinction risk to species is estimated to have arisen in the past 40 years (*established but incomplete*).

3 **The degree of transformation of ecosystems from natural to human-dominated varies widely across terrestrial, inland water and marine systems, and geographically within many systems {2.2.5.2.1, 2.2.7}. Over 30% of the world's land is now agricultural or urban, with ecosystem processes deliberately redirected from natural to anthropogenic pathways. Human drivers extend so widely beyond these areas that as little as 13% of the ocean and 23% of the land is still classified as "wilderness" – and these areas tend to be remote and/or unproductive (e.g., tundra, oceanic gyres) *(well established)* {2.2.5.2.1}.** The most accessible and hospitable biomes either have been almost totally modified by humans in most regions (e.g., Mediterranean forests and scrub, temperate forests) or show maximum levels of conversion to anthropogenic biomes or "anthromes" (e.g., conversion of most temperate grassland to cultivated land and urban areas) *(well established)* {2.2.7.7}. Although the five freshwater and marine biomes cannot be settled and physically transformed in the same way as terrestrial biomes, they too range from unaltered to highly degraded *(well established)* {2.2.5.2.1, 2.2.7}. No global data exist on the extent of aquaculture and intensively-used coastlines, but sensitive coastal and nearshore ecosystems – such as coral reefs, mangroves and saltmarshes – are already well below natural baseline levels and continuing to decline rapidly *(established but incomplete)* {2.2.5.2.1}. Such habitats provide important resources and protection for hundreds of millions of people.

4 **Globally, the net rate of loss of forests that are not managed for timber or agricultural extraction has halved since the 1990s (*established but incomplete)*, but declines continue in the tropics *(well established)*; and intact forest landscapes – large areas of forest or natural mosaic with no human-caused alteration or fragmentation detectable by satellites – are still being lost from both high and low income countries *(established but incomplete)* {2.2.5.2.2}.** Forests in temperate and high latitudes have been expanding through afforestation programmes or vegetation succession after land abandonment, but the often highly biodiverse tropical forests continue to dwindle (*well established*) {2.2.5.2.1, 2.2.7.2}. The rate of loss of intact tropical forest landscapes has increased threefold in 10 years due to industrial logging, agricultural expansion, fire and mining (*well established*) {2.2.5.2.1}. Primary boreal and temperate forests are also increasingly degraded worldwide *(well established)* {2.2.7.3}.

5 **Hotspots of rare and endemic species have on average suffered more degradation of ecosystem structure and biotic integrity than other areas, despite their importance for global biodiversity *(well established)* {2.2.5.2, 2.2.7.15}.** Across a range of taxonomic groups, 7.3% of the land is particularly rich in

species that are not found elsewhere. Indicators of ecosystem structure, community composition and species populations are ~ 20% lower in these 'hotspots' of rare and endemic species and are declining much faster (median = 74% faster), than across the world as a whole *(established but incomplete)* {2.2.5.2}. In the oceans, approximately half the live coral cover on coral reefs – among the most species-rich habitats on earth – has been lost since the 1870s, with accelerating losses in recent decades due to climate change exacerbating other drivers; the live coral cover on coral reefs has declined by 4% per decade since 1990 *(established but incomplete)* {2.2.5.2.1}.

6 **Human actions threaten more species with global extinction now than ever before *(well established)* {2.2.5.2.4}: extrapolating from detailed 'bottom-up' assessments of species in the best-studied taxonomic groups suggests that around one million animal and plant species already face extinction, and that a third of the total species extinction risk to date has arisen in the last 25 years *(established but incomplete)* {2.2.5.2.4}.** Land/sea-use change is the most common direct driver threatening assessed species, followed by (in descending order of prevalence) direct exploitation, pollution, invasive alien species and climate change *(well established)* {2.2.6}. The rate of species extinction is already at least tens to hundreds of times higher than it has averaged over the past 10 million years, and it is set to rise sharply still further unless drivers are reduced *(well established)* {2.2.5.2.4}. Available population trend records show widespread and rapid declines in species' distributions and population sizes *(established but incomplete)* {2.2.5.2.4}; these declines can both reduce the contributions species make to people and perturb local ecosystems with often unpredictable results**.** The prevalence of extinction risk in high-diversity insect groups is a key unknown, and knowledge of population trends is still very incomplete, especially for non-vertebrate species.

7 **A 'top-down' analysis of the number of species for which sufficient habitat remains suggests that as many as half a million terrestrial species of animal and plant may already be doomed to extinction because of habitat loss and deterioration that have already taken place *(established but incomplete)* {2.2.5.2.4}.** These 'dead species walking' come about because responses to drivers can take many years to play out *(well established)* {2.2.5.2.4}. Habitat restoration could save many of these species if done soon after the original loss or degradation of habitat. The estimate of half a million terrestrial species, including over 3,000 vertebrate and 40,000 plant species, is produced by unprecedented integration of global environmental data with distributional information for over 400,000 terrestrial species of invertebrate, vertebrate and plant; although it is broadly consistent with the 'bottom-up' estimate of a million threatened species across the terrestrial, freshwater and marine realms, it uses entirely separate data and analysis.

8 **Transformation of ecosystems to increasingly intensive human use has enabled a small fraction of species to greatly expand their distribution and increase in abundance.** Nearly one fifth of the Earth's surface is at risk of plant and animal invasions, impacting native species, ecosystem functions and nature's contributions to people, as well as economies and human health. Over 6000 plant species are known to be invasive somewhere in the world. The number of invasive alien species and the rate of introduction of new invasive alien species seems higher than ever before and with no signs of slowing *(established but incomplete)* {2.2.5.2.3}.

9 **Human actions are driving widespread changes in organismal traits *(well established)* {2.2.5.2.5} and reductions in genetic diversity *(established but incomplete)* {2.2.5.2.6}. Many species are evolving rapidly as they adapt to human drivers of change, including some changes – such as resistance to antibiotics and pesticides – that pose serious risks for society *(well established)* {2.2.5.2.5, Box 2.5}, which evolutionary-aware policy decisions and strategies can mitigate *(established but incomplete).*** Populations have lost about 1% of their genetic diversity per decade since the mid-19th century; wild populations whose habitats have been fragmented by land-use change have less genetic diversity than those elsewhere; and mammalian and amphibian genetic diversity is lower where human influence is greater *(established but incomplete)* {2.2.5.2.6}. Although the spread of agriculture led to the development of many races and varieties of farmed animals and plants, the modernization of agriculture has seen many of these go extinct: by 2016, 559 of the 6,190 domesticated breeds of mammals used for food and agriculture (over 9 per cent) had become extinct and at least 1,000 more are threatened *(established but incomplete)* {2.2.5.2.6}. Case studies have demonstrated rapid trait changes in response to all main direct drivers and some clear examples of rapid evolution – e.g., trophy-hunted bighorn sheep have evolved smaller horns – and many species show rapid evolution in cities *(well established)* {2.2.5.2.5, **Box 2.5**}. Evolutionary-aware strategies can help to prevent undesirable evolution (e.g., of resistance to control measures in pests and diseases) and to promote desirable evolutionary outcomes (e.g., reduced reproduction of mosquitoes that transmit malaria) *(established but incomplete)* **{Box 2.5}**.

10 **The global loss of forests, rates of species extinction, and average losses of originally-present biodiversity from terrestrial ecological communities all transgress proposed precautionary 'Planetary Boundaries' *(established but incomplete)* {2.2.5.2.1,**

2.2.5.2.3}. Transgressing these boundaries may risk tipping the Earth system out of the environmentally stable state it has been in throughout the history of civilization, though debate about both the reality and position of the boundaries continues *(inconclusive)* {2.2.5.2.1, 2.2.5.2.3}***.*** The loss of forests and tree cover (reduced to 68% and 54%, respectively, of their historical baselines) exceed the proposed Planetary Boundary for land-system change (i.e., no more than a 25% reduction in forests) *(established but incomplete)* {2.2.5.2.1}, below which the biosphere's contribution to global climate regulation may become critically compromised *(unresolved)* {2.2.5.2.1}. The global rate of species extinction is already at least tens to hundreds of times higher than the average rate over the past 10 million years and is accelerating *(established but incomplete)* {2.2.5.2.4}, exceeding the proposed boundary and potentially impoverishing the biosphere's capacity to adapt to possibly abrupt environmental change *(unresolved)* {2.2.5.2.4}. On average, terrestrial ecological communities worldwide have lost at least 20% of their originally-present biodiversity *(established but incomplete)* {2.2.5.2.3}, double the proposed safe limit beyond which the short-term healthy functioning of biomes may become compromised *(inconclusive)* {2.2.5.2.3}.

11 **Land-use change has had the largest relative negative impact on nature for terrestrial and freshwater ecosystems, mainly through habitat loss and degradation; whereas in marine ecosystems, direct exploitation of organisms (mainly fishing) has had the largest relative impact, followed by land/sea-use change *(well established)* {2.2.6.2}. The multiple components of climate and atmospheric change (e.g., changing temperature, rainfall and atmospheric CO_2 levels as well as ocean acidification) are already significant drivers of change in many aspects of nature but are not usually the most important drivers at present (*well established*) {2.2.6.2}.** The relative impact attributable to each driver also varies markedly among components of nature, taxonomic groups, regions and biomes (*established but incomplete*) {2.2.6.2, 2.2.7}. For instance, species abundance is mostly affected by land-use change in the terrestrial and freshwater systems but by direct exploitation in the marine realm. Invasive alien species often have a strong impact on oceanic island assemblages worldwide (*well established*) {2.2.3.4.1, 2.2.5.2.3}, and invasive pathogens are implicated in the rapid declines of many amphibian species (*well established*) {2.2.5.2.3}. Coral reef bleaching is a direct consequence of ocean temperature increase *(well established)* {2.2.7.15}. Temperature increase is the main factor at high latitudes both on land and in the oceans {2.2.5.2.5, 2.2.7.3, 2.2.7.5, 2.2.7.12, 2.2.7.15}. The drivers of change are all interconnected; as such they are compromising the Earth's living systems as a whole to a degree unprecedented in human history.

12 **The world's major ecosystems vary in both the intensity of drivers they face and their ability to withstand them, with some close to potential collapse.** The bleaching of shallow coral reefs during hotter and more frequent marine heat waves, coupled with intensifying fishing and intensification of coastline use, indicate a type of ecosystem whose thresholds of resilience are being exceeded *(well established*) {2.2.7.15}. In the Mediterranean forests, woodlands and scrub of many regions, wildfires are starting earlier in the year and increasing in number, coverage and severity which, coupled with their increasing human population due to attractiveness for settlement and the associated expansion of urban and cultivated areas, may indicate a transformation at the biome scale *(established but incomplete)* {2.2.7.4}.

13 **Many practices of Indigenous Peoples and Local Communities (IPLCs) conserve and sustainably manage, wild and domesticated biodiversity *(well established)* {2.2.4}. A high proportion of the world's terrestrial biodiversity lives in areas managed and/or held by Indigenous Peoples *(well established)* {2.2.4}, where ecosystems and ecological communities tend to be more intact and declining less rapidly than elsewhere *(established but incomplete)* {2.2.5.3.1}.** Practices that contribute to biodiversity include co-production of highly diverse cultural landscapes that are very heterogeneous ecologically and often rich in both wild and domesticated species {2.2.4.1, 2.2.4.2, 2.2.4.3}; contributing to agrobiodiversity by selection, domestication and maintenance of wild races and varieties of plants and animals {2.2.4.4}; traditional management practices that enhance natural resilience (e.g., by targeted burning) {2.2.4.5}; increasing landscape-scale net primary biomass production (e.g., by adaptive grazing and burning regimes) {2.2.4.6}; and protecting areas from external exploiters, e.g., slowing the spread of intensive monocrop agriculture in recognized indigenous territories {2.2.4.7}. However, unsustainable practices are becoming increasingly common in some regions traditionally managed by Indigenous Peoples and Local Communities as lifestyles, values and external pressures change with globalization *(well established)* {2.2.4}. At least a quarter of the global land area is traditionally owned, managed[1], used or occupied by Indigenous Peoples. These areas include approximately 35 per cent of the area that is formally protected, and approximately 35 per cent of all remaining terrestrial areas with very low human intervention (*established but incomplete*) {2.2.5.3.1}; all these figures would rise if other local communities were considered*.* For the global indicators that could be compared between these indigenous lands

1. These data sources define land management here as the process of determining the use, development and care of land resources in a manner that fulfils material and non-material cultural needs, including livelihood activities such as hunting, fishing, gathering, resource harvesting, pastoralism and small-scale agriculture and horticulture.

and the world as a whole, nature has declined by 30% less, and has declined 30% more slowly in recent years, in the indigenous lands *(established but incomplete)* {2.2.5.3.1}.

14 **Indigenous Peoples and Local Communities report that the nature important to them is mostly declining: among the local indicators developed and used by Indigenous Peoples and Local Communities, 72 per cent show negative trends in nature that underpin local livelihoods and well-being *(well established)* {2.2.5.3.2}, which they mainly attribute to land-use change and climate change; the relative importance of these drivers varies among regions and major ecosystem types *(established but incomplete)* {2.2.6.3}.** Natural resource availability is generally decreasing; time needed or distance travelled to harvest resources is increasing; culturally salient species often have negative population trends; native newcomer species arrive as climate changes (e.g., southern species to arctic areas); new pests and invasive alien species colonize; natural habitats are lost, especially forests and grazing lands, while remnant ecosystems degrade and their productivity decreases; and the health condition and body size of wild animals decrease *(established but incomplete)* {2.2.5.3.2}. The drivers to which IPLCs most often attribute the mostly negative trends in nature (in decreasing order of prevalence and based on >300 indicators) were land-use change (e.g., tropical forest monocrop conversions, expansion of settlements and discontinued traditional land management practices); climatic changes, such as droughts and the increasingly unpredictable annual distribution of rainfall; arrival of new pests and invasive alien species; changing range of wild species; floods (as a combined effect of climate and land-use changes); and finally overexploitation of resources by outsiders and locals (e.g., logging and overgrazing) *(established but incomplete)* {2.2.6.3}.

15 **Whereas scientific observations on the status of nature have for centuries been valued, systematically recorded, retained and synthesized in scientific outputs, indigenous and local knowledge of nature has been largely disregarded, is still being lost, and has rarely been synthesized (*well established)* {2.2.2.2}.** The synthesis of trends in nature observed by Indigenous Peoples and Local Communities has been hindered by the lack of regional and global institutions that would gather, aggregate and synthesize local data into regional and global summaries *(well established)* {2.2.2.2, **Box 2.6**}, but such efforts are emerging. Many of the aspects of nature monitored by Indigenous Peoples and Local Communities are reasonably compatible with indicators used by natural scientists but tend to be more local in scale and more directly connected to elements of nature that underpin nature's contributions to people (*well established)* **{Box 2.6}**, highlighting the importance of recording and synthesizing them. The spread of modern lifestyles and technologies into many indigenous and other local communities may threaten the current diversity of conceptualizations of nature and of ways of learning about and from it, as well as resource management practices that could ensure sustainable human-nature relations (*well established*) {2.2.2; 2.2.4}.

16 **This global assessment has been able to make use of much more, better, more comprehensive and more representative information than was available even a decade ago *(well established)* {2.2.1}. Though uncertainties and gaps in knowledge remain, there can be no doubt that nature is continuing to decline globally *(well established)* {2.2.5, 2.2.7} in response to direct human-caused drivers *(well-established)* {2.2.6}.** Some of the most important knowledge gaps are: global syntheses of indigenous and local knowledge about the status and trends in nature; quantitative syntheses of the status and trends of parasites, insects, microorganisms, and biodiversity in soil, benthic and freshwater environments, and of the implications for ecosystem functions; quantitative syntheses of human effects on ecosystem processes involving interactions among species, e.g., pollination; quantitative global overviews of many vital ecosystem functions; syntheses of how human impacts affect organismal traits and genetic composition; and a more comprehensive understanding of how human-caused changes to one Essential Biodiversity Variable class (e.g., ecosystem structure) ramify through to the others (e.g., community composition) and to nature's contributions to people.

2.2.1 INTRODUCTION

The definition of 'nature' used in this assessment encompasses all the living components of the natural world. Within the context of western science, it includes biodiversity, ecosystems (both structure and functioning), evolution, the biosphere, humankind's shared evolutionary heritage, and biocultural diversity (Díaz *et al.*, 2015). Within the context of other knowledge systems, such as those of Indigenous Peoples and Local Communities (IPLCs), nature includes categories such as Mother Earth and systems of life, and it is often viewed as inextricably linked to humans, rather than as a separate entity (Díaz *et al.*, 2015). IPBES' mandate includes bringing together evidence from diverse knowledge systems, including indigenous and local knowledge, and respecting diverse worldviews. Section 2.2.2 explores the diversity of worldviews and of ways in which nature is conceptualized and outlines how they are changing.

Nature shows enormous geographic variation, at both large and small spatial scales. Associated with the range of spatial scales, there are also a broad array of institutions and governance of nature, varying from local communities through to international **(Figure 2.2.1)**, which all mediate both how nature contributes to people (NCP) and how people affect the state of nature (Brondizio *et al.*, 2009; Duraiappah *et al.*, 2014; see chapters 2.1 and 2.3). At the broadest geographic scale, nature can be described according to different units of analysis (defined in chapter 1) – from coniferous and temperate forests to tropical and subtropical savannas to coastal areas and deep oceans. However, within each of these units, there is variation among regions, landscapes and habitats (both terrestrial and marine) and at all levels of diversity. Section 2.2.3 tackles this complexity, organising nature's many dimensions into six classes – ecosystem structure, ecosystem function, community composition, species populations, organismal traits and genetic composition (Pereira *et al.*, 2013) – and outlines how the global patterns of each today still largely reflects the action of natural evolutionary and ecological processes through earth's history (Bowen *et al.*, 2013; Pinheiro *et al.*, 2017; Rex & Etter, 2010; Ricklefs, 2004; Whittaker *et al.*, 2001; Willig *et al.*, 2003). Illustrative examples mostly highlight aspects of nature that underpin some of its most critical material, non-material and regulating contributions to people.

Humanity has been reshaping patterns in nature for many millennia (Lyons *et al.*, 2016). Many IPLCs view themselves as partners in a reciprocal process of nurturing and co-production, rather than as extrinsic drivers of change (see chapter 1). Section 2.2.4 describes the land- and sea-management practices and processes through which IPLCs have co-produced and maintained nature and continue to do so over much of the world. At least a quarter of the global land area is traditionally owned, managed[2], used or occupied by Indigenous Peoples (at least double if local communities are considered). These areas include approximately 35 per cent of the area that is formally protected, and approximately 35 per cent of all remaining terrestrial areas with very low human intervention (Garnett *et al.*, 2018).

Whether viewed as an extrinsic driver or an intrinsic part of nature, humanity's actions now increasingly overprint the global patterns that natural processes have produced, at all scales **(Figure 2.2.1)**. Section 2.2.5 considers human-caused trends in nature alongside current status. Because many anthropogenic drivers of change have intensified greatly since the mid-20th century (chapter 2.1, Steffen *et al.*, 2015a), the discussion of trends focuses on changes since 1970, but also briefly describes earlier positive and negative effects. As well as many science-based indicators, this section includes the first global synthesis of local trend indicators observed by IPLCs. Section 2.2.6 synthesizes which of the main direct drivers – land/sea-use change, direct exploitation, climate change, pollution and invasive alien species (see chapter 2.1) have had the greatest relative impact on nature in recent decades as judged by analysis of global indicators and the perceptions of IPLCs of the drivers behind the local changes they observe.

This subchapter's mostly global focus is balanced by brief accounts of the status, trends and drivers of change in nature within each unit of analysis (Section 2.2.7), and by also highlighting three other categories of landscape that add to global nature and nature's contributions to people disproportionately to their geographic extent: insular systems, areas particularly rich in endemic species, and hotspots of agrobiodiversity (Section 2.2.3.4). The contribution of agrobiodiversity to people is obvious; but nature contributes to people in a myriad of ways, from local-scale flows of material and non-material benefits to households and communities, to global-scale regulation of the climate **(Figure 2.2.1)**; chapter 2.3 synthesizes these contributions and how the trends in nature are changing them.

Synthesizing and mapping variations in the state of nature across the globe and over time has been greatly facilitated by major recent advances in remote observation of biodiversity and ecosystems, in modelling and in informatics. For example, remote-sensing technologies can now provide data on ecosystem structure and function – and increasingly on abundance and distribution of biodiversity – across wide areas, with high spatial and temporal resolution (Pettorelli *et*

2. These data sources define land management here as the process of determining the use, development and care of land resources in a manner that fulfils material and non-material cultural needs, including livelihood activities such as hunting, fishing, gathering, resource harvesting, pastoralism and small-scale agriculture and horticulture.

al., 2016), though deriving estimates of global biodiversity change from remotely-sensed data is not yet straightforward (Rocchini *et al.*, 2015). Recording of indigenous and local knowledge (Lundquist *et al.*, 2016) can also add relevant information over smaller scales. In addition, advances in species delimitation, identification and discovery have been facilitated by new DNA technologies (e.g., Kress *et al.*, 2015) and this in conjunction with data aggregators and repositories, such as GBIF (www.gbif.org), OBIS (www.iobis.org) and Genbank (Benson *et al.*, 2013), make hundreds of millions of species occurrence records and gene sequences freely available. Ever-improving metadata mean that such data – despite still providing very uneven coverage taxonomically, geographically, temporally and ecologically (Akçakaya *et al.*, 2016; Hortal *et al.*, 2015) – can increasingly be put to a wide range of uses. This expanded biodiversity informatics landscape is increasingly well connected (Bingham *et al.*, 2017), facilitating the synthesis of raw observations by new analytical interfaces (e.g., Jetz *et al.*, 2012; Ratnasingham & Hebert, 2007; see www.iobis.org).

A growth in multi-institution collaboration has also resulted in the expansion of networks collecting parallel data, often in many countries (e.g., Anderson-Teixeira *et al.*, 2015; Kattge *et al.*, 2011), while the establishment of the Biodiversity Indicators Partnership and GEO BON has helped to coordinate biodiversity observations, modelling and indicators (Mace & Baillie, 2007; Pereira *et al.*, 2013; Scholes *et al.*, 2008). The development and widespread adoption of meta-analyses and systematic reviews – facilitated by bibliographic databases, online publishing and the growth of open data – has helped researchers to synthesize previously disparate evidence (e.g., Gibson *et al.*, 2011; Root *et al.*, 2003). Synthesis of indigenous and local knowledge on status and trends of nature unfortunately still lags much behind scientific synthesis, though much progress is underway in documenting local observations of trends and aggregating these to global scale (see e.g., Forest Peoples Programme *et al.*, 2016a), and co-producing knowledge from ILK and science.

These developments in observation, aggregation, collaboration, modelling and synthesis mean that this global assessment has been able to draw on much better and more integrated information than was possible even only a decade ago.

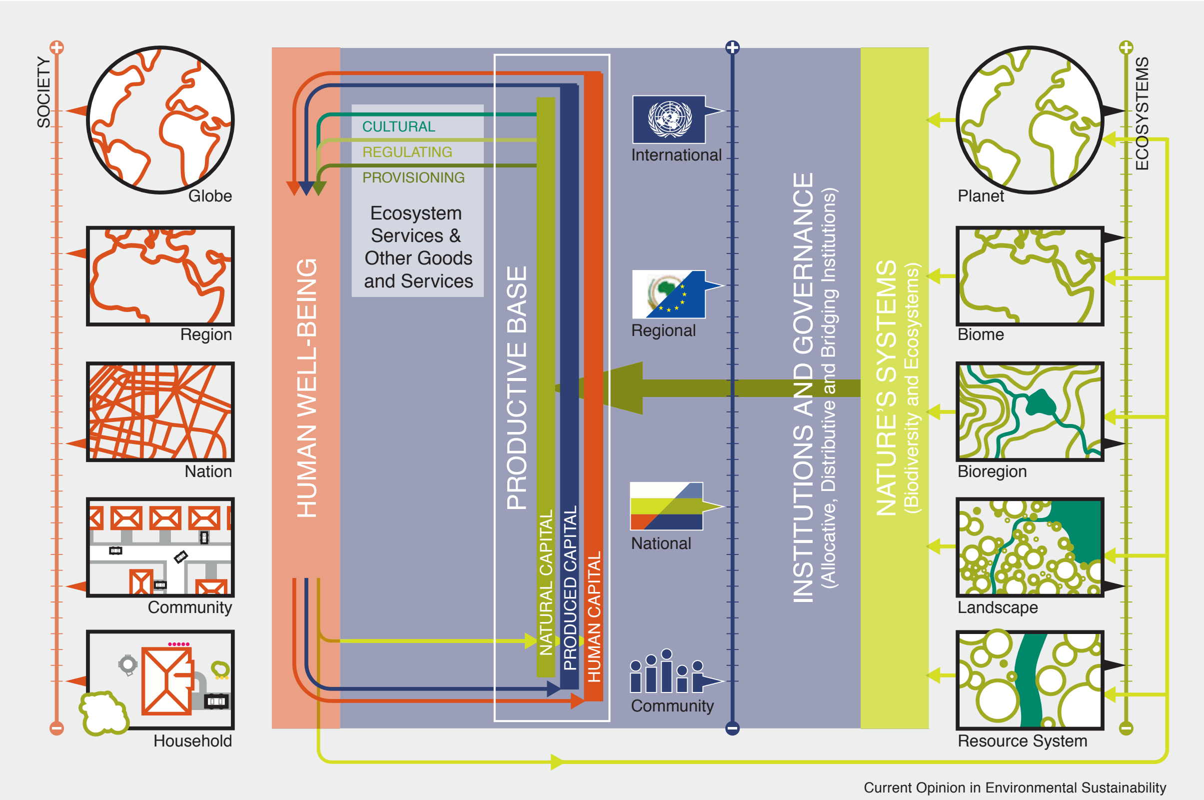


Figure 2 2 1 **The hierarchical scales of nature, society and governance.**

This figure has many parallels with the IPBES conceptual framework (see chapter 1), but emphasises how the multiple scales of governance influence both nature's contributions to people (arrows passing through the box labelled 'Ecosystem services & other goods and services) and societal feedbacks onto nature's systems. Figure from Duraiappah *et al.* (2014).

2.2.2 DIVERSE CONCEPTUALIZATIONS OF NATURE AND PLURALISTIC KNOWLEDGE SYSTEMS

Nature is conceptualized differently by people having different relationships with it, including farmers, herders, fishers, hunter-gatherers, other Indigenous Peoples and Local Communities, urban communities, practitioners (such as hydro- and forest engineers), natural scientists, social scientists and artists. Different conceptualizations of nature lead to different types of experiential learnings and knowledge systems. Within historical times some knowledge systems such as "scientific knowledge", have gained a universal acknowledgement, while other knowledge systems such as "indigenous knowledge" have been less well appreciated and valued, especially in terms of the information they provide on nature both locally and at larger scales.

2.2.2.1 Indigenous Peoples' and Local Communities' conceptualizations and knowledges of nature (IPLCs)

There are many different ways that societies consider nature. There are those which consider humans as an element of nature. In contrast, others consider humans as starkly different from nature beyond the obvious biological commonalities with, and dependence on, the rest of the living world. Here we use the term 'conceptualizations of nature' to refer to views and perspectives on nature by different societies, which establish meanings to the links between humans and elements of nature, and form principles or ontologies that guide interactions with nature (Atran *et al.*, 2002; Ellen & Fukui, 1996; Foucault, 1966). Anthropological studies comparing many societies across the world have classified the large diversity of situations met into general models, based on the degree of continuity or separation between nature and people. Most societies that recognize a continuity between humans and nature conceptualize elements of nature as agents with an interiority, intentions or an attractivity (e.g., plants) that facilitates interactions between humans and non-human (Descola, 2013; Ellen, 2006). Models showing strong linkages between humans and non-humans are for instance animism and totemism (Descola, 2013; Harvey, 2006; Sahlins, 2014). Analogism, a widespread conception of nature widely studied and typical of some Asian societies and in Europe differentiates humans and non-humans although they share some properties from microcosms (cells) to macrocosms (planets) and are made of similar elements (wind, water, fire etc.). Within such conceptualizations humans are able to find in nature many signs that guide a large set of practices, including health, food, agriculture (e.g., Friedberg, 2007; Zimmermann, 1988). Naturalism – the principle that theoretically characterizes modern western societies and western science – emerged with philosophers such as Descartes and emergence of modernity – conceives natural as an external element, starkly different from humans, an object of experimentation using analytical approaches for better productivity or control (Foucault, 1966).

Such principles continue to influence people's attitudes to environmental and sustainability issues today. While science is therefore supposed to be neutral, Ellen (1996), shows that scientific disciplines have their own ways of conceiving the environment that serve the interest of particular groups, whether they belong to the conservation movement, have linkages to industries, churches, political parties, academics, Indigenous People, or governments. Thus, even science and modernity establish intricate links between nature and culture and the naturalist approach is rarely void of cultural worldviews.

The IPBES conceptual framework puts a strong emphasis on reflecting that different societies, and different individuals within societies, have different views on desirable relationships with nature, the material versus the spiritual domain, and the present versus the past or future (Díaz *et al.*, 2015, 2018; see also chapter 1, Section 1.3.1).

Indigenous and local knowledge systems are the knowledge of Indigenous Peoples and Local Communities who mostly live within natural and rural environments and make a living through – and define their cultural identity upon – an intimate relationship with nature, land and sea (Douglas *et al.*, 1999; Garnett *et al.*, 2018; Sanga & Ortalli, 2003; Warren & Slikkerveer, 1995). Indigenous knowledge systems differ from science in many ways, viewing nature holistically i.e., as said above linking all elements of nature to people in ways that enables continuities either through considering the inner self of non-humans (animism and totemism) or through common properties (analogism), all of which are linked to the social and decision-making spheres (Descola & Palsson, 1996; Ellen, 2002; Motte-Florac *et al.*, 2012; Tengö *et al.*, 2017; see more in chapter 1). Building upon similar overall principles linking humans to nature, local knowledge systems are locally rooted, tested and culturally transmitted (Molnar & Berkes, 2018). Many of these local knowledge systems vary depending on sociocultural and religious background and also the degree of integration in modern lifestyles, a situation also encountered among indigenous groups. For example, European small-scale multi-generational farmers, herders and fishers, and some foresters and hydro-engineers using and managing the same natural resource for generations may have strong connections to their local nature and a deep understanding of local ecological processes and may feel themselves as part of nature (Babai & Molnár, 2014; Kis *et al.*, 2017; Whiteman & Cooper, 2000).

2.2.2.2 Collaboration between knowledge systems, changing conceptualizations

Conceptualizations of nature and related knowledge and practices are not static. They may change considerably over time at different temporal scales. Knowledge co-production between knowledge systems, interdisciplinary cooperation and modern lifestyles may accelerate change, and may foster or threaten conceptualizations and knowledge that ensure sustainable human-nature relations and consequently status and trends in nature.

Conceptualizations of nature may change in relation to levels of collaboration between knowledge systems and/ or between scientific disciplines. Although disciplinary approaches in natural or social sciences (e.g., between functional and evolutionary ecology, sociology and

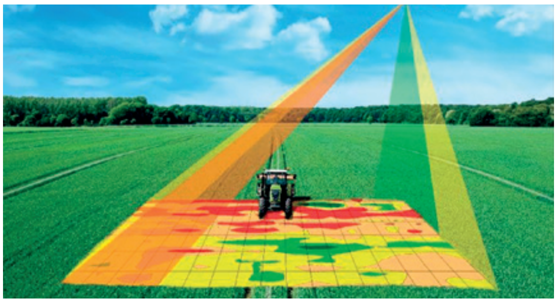
Box 2 1 Conceptualizations of nature – examples.

Conceptualizations of nature – whether indigenous, scientific, laic, practitioner or something else – have a fundamental impact on our behaviour, relations to nature and thus on our impact on nature. Examples in this box aim to present some contrasting conceptualizations of nature.

In Indigenous conceptualizations of nature people often argue: 'All is One', 'All is connected'. April White, a Haida Indigenous artist from British Columbia created a series of prints to help negotiations of Haida fishery management with the government. These prints feature a herring-consuming predator (e.g., a whale) inside of a herring, a way reflecting the nurturing role the fish plays for so many organisms at all levels of the ecosystem. She argues that art possesses a unique storytelling power that science can stand from benefit from, "Art has a voice where a scientist might not." (Vogl, 2017).

The romantic idyllic view of nature emphasizes purity of nature, laws of nature, and harmony. This view had a huge impact on the notion of 'balance of nature' (cf. also Carson's Silent Spring), and the development of some wilderness-oriented protected area management philosophies (source: Károly Telepy, Rocky landscape, 1870, @KOGART).

Perspectives matter. Those who experienced this view of our Earth often argue for a shift in their perspective: "You also notice how the atmosphere looks and how fragile it looks," astronaut Scott Kelly said. "It makes you more of an environmentalist after spending so much time looking down at our planet." (https://mashable.com/2016/03/04/scott-kelly-year-space-environmentalist/?europe=true). (Earthrise from the moon during Apollo 8, NASA).



Precision agriculture is becoming one of the dominant views about arable areas in our modern era. It aims to provide enough food for humanity with a very high level of anthropogenic assets, dominating natural processes with advanced technology. This conceptualization also changes considerably our relations to the nature we manage (source: https://www.innovationtoronto.com/2016/09/precision-agriculture/).

economics) are often still dominant, the trends towards collaborative, inter- and transdisciplinary and participatory research with stakeholders on nature and human-nature relations are now opening new options for learning. This may help develop new concepts of interactions between nature and humans that foster social-ecological systems and resilience thinking (Berkes *et al.*, 2000), relational thinking (Chan *et al.*, 2016), deep ecology (Naess, 1973), the revisiting of the religious linkage to nature through portraying the ideas of Saint Francis of Assisi (Francis, 2015) or the pluralistic IPBES concept of nature's contributions to people (Díaz *et al.*, 2018). Within conservation biology, views on the relationship between people and nature have continued to change over recent decades: nature for itself, nature despite people, nature for people, and people and nature (Mace, 2014). Some conservation biologists integrate indigenous and local knowledge to help develop new concepts and practical actions for better conservation (Ghimire *et al.*, 2008; Molnár *et al.*, 2016). In ethnobiology, a discipline dedicated to study human-nature relations, there is a shift from more academic research objectives to more practical approaches including working together with Indigenous Peoples and Local Communities to co-develop sustainable management practices (Barrios *et al.*, 2012; Berkes, 2004; Hamilton & Hamilton, 2006; Newing *et al.*, 2011).

Global processes include different contrasting tendencies such as commodification of nature, urbanization, spread of modern lifestyles, green movements, respect for the rights of Mother Nature (such as allocating personhood status to rivers), and wider acknowledgment of local space-based knowledge systems linked to complexity of social-ecological systems. These tendencies are likely to change human-nature relations and our conceptualizations of nature. In addition, hybridization of scientific and indigenous and local knowledge of nature is accelerating all over the world and changing our values regarding nature.

Although indigenous and local knowledge (ILK) is locally-based, it is increasingly being shared between holder groups through local to global networks (e.g., Forest Peoples Programme *et al.*, 2016a; ICCA Consortium: www.iccaconsortium.org), and by social media.

People living in urban settings also have diverse and changing conceptualizations of nature depending on their ethnic and family history, education, religion, and their everyday experiences with urban and non-urban nature and modern technology (Coyle, 2005; Loughland *et al.*, 2003).

Scientific observations on the state of nature from a scientific perspective have for centuries been valued, systematically recorded, retained in the accumulating scientific literature and synthesized. In contrast, much indigenous and local knowledge has not been recorded in a systematic fashion and thus much knowledge has been lost (see more in chapter 3 and 6). This means that records and synthesis lag far behind natural science, so there are very few resources on the status and trends of nature as observed by Indigenous Peoples and Local Communities with global coverage (Forest Peoples Programme *et al.*, 2016a; Posey, 1999). Because of this imbalance, although most of the evidence in this chapter came from the context of natural sciences, a special effort has been made to also accommodate indigenous and local knowledge on nature.

2.2.3 OVERVIEW OF NATURE

2.2.3.1 Essential Biodiversity Variables

Given the complexity of unit and scale when considering nature, a global system of harmonized observations has been proposed for the study, reporting, and management of biodiversity change (Pereira *et al.*, 2013). These have been termed 'Essential Biodiversity Variables' (EBV) (see https://portal.geobon.org) **(Figure 2.2.2)**. Below we describe what is known about the current global distribution of nature using this framework, giving examples of the current knowledge on those aspects of the variables that are particularly important in terms of NCP. We then go onto discuss the contribution of Indigenous People and Local Communities to the co-production and maintenance of nature, particularly genetic, species and ecosystem diversity. This is followed by a discussion on the status and trends in nature based on these EBVs with particular emphasis on the past 50 years – trends that have resulted in the current state of nature.

2.2.3.2 Ecosystem structure

At the global scale, the terrestrial realm can be demarcated according a pattern of ecosystem structure (Units of Analysis) **(Figure 2.2.2A)** where different dominant species cause the ecosystems to differ in structural complexity (e.g., tropical rainforest vs tundra or deserts) and the natural resources they can provide to people. Sometimes referred to as 'biomes' (Olson *et al.*, 2001) and (for anthropogenic units) 'anthromes' (Ellis & Ramankutty, 2008), the current observed units of structural complexity across the globe occur as result of processes that span millions of years and primarily reflect a combination of water-energy dynamics, geology and tectonic activity (Willis & McElwain, 2014). Demarcation of marine biomes according to ecosystem structure is an ongoing task – new habitats are still being discovered (Costello *et al.*, 2010; Snelgrove, 2016) – but here too, long-term environmental and geological processes determine structure: e.g., warm-water shallow coral reefs can grow only within a narrow environmental envelope (Kennedy *et al.*, 2013).

An understanding of global ecosystem structure is particularly important in determination of variations in photosynthetic biomass. These variations in biomass in turn have many effects on multiple aspects of NCP, from the type and quantity of material and non-material benefits available to local people, to global regulation of climates through carbon sequestration and the water cycle (Pan *et al.*, 2011, 2013). Total photosynthetic biomass in the ocean is less than 1% of that on land (totals of 3 PgC for marine versus 450–650 PgC on land), and this amount is mostly regulated by nutrient availability, light availability and temperature (IPCC, 2013).

2.2.3.3 Ecosystem function

This term is used to describe functions provided by the stocks of materials in an ecosystem (e.g., carbon, water, minerals, and nutrients) and the flows of energy through them. The functioning of an ecosystem is therefore reliant upon a complex array of abiotic and biotic factors and underpinned by many of the variables of nature described below. When considering global ecosystem functions that are important to people, two of the most fundamental are net primary production (NPP) and carbon sequestration.

Net primary production (NPP) represents the uptake of CO_2 by plants during photosynthesis minus the amount of CO_2 that is lost during respiration. Its importance is that it provides the main source of food for non-photosynthetic organisms in any ecosystem – including humans. NPP therefore underpins many critical aspects of nature's contribution to people (Imhoff *et al.*, 2004). Worldwide, humanity now appropriates 24% of terrestrial NPP, with over 50% being appropriated across many of the intensively farmed regions (Haberl *et al.*, 2007). NPP shows very large spatial variation **(Figure 2.2.2B)**. Terrestrial NPP varies from < 100 gC/m2/year (in polar and desert regions) to 1500 gC/m2/year in the humid tropics (Zak *et al.*, 2008) (see also **Table 2.2.2**), in response to levels of sunlight, temperature, water availability, CO2, nutrient availability and the type of vegetation (Nemani *et al.*, 2003). In the oceans, NPP is largely determined by nutrient availability (e.g., Howarth, 1988; Huston & Wolverton, 2009), varying from undetectably low in nutrient-poor gyres to 500 gC/m2/year in the coastal shelves and upwelling regions.

Carbon sequestration is another critically important global ecosystem function provided by nature. This represents the difference between CO_2 uptake by photosynthesis and release by respiration, decomposition, river export and anthropogenic processes such as harvesting and biomass burning. At present about 60% of the atmospheric CO_2 emitted into the atmosphere by fossil fuel emission each year (9.4 PgC / year in 2008–2017) is sequestered by nature's carbon sink in land (3.2 PgC /year in 2008–2017) and in the oceans (2.4 PgC / year in 2008–2017) (Le Quéré *et al.*, 2018), providing a vital role in regulating the Earth's climate.

Spatial and temporal patterns in carbon sinks and sources are very heterogeneous. Forest ecosystems (e.g., tropical and boreal forests) on average are carbon sinks due to CO_2 fertilization, climate change, and recovery from historical

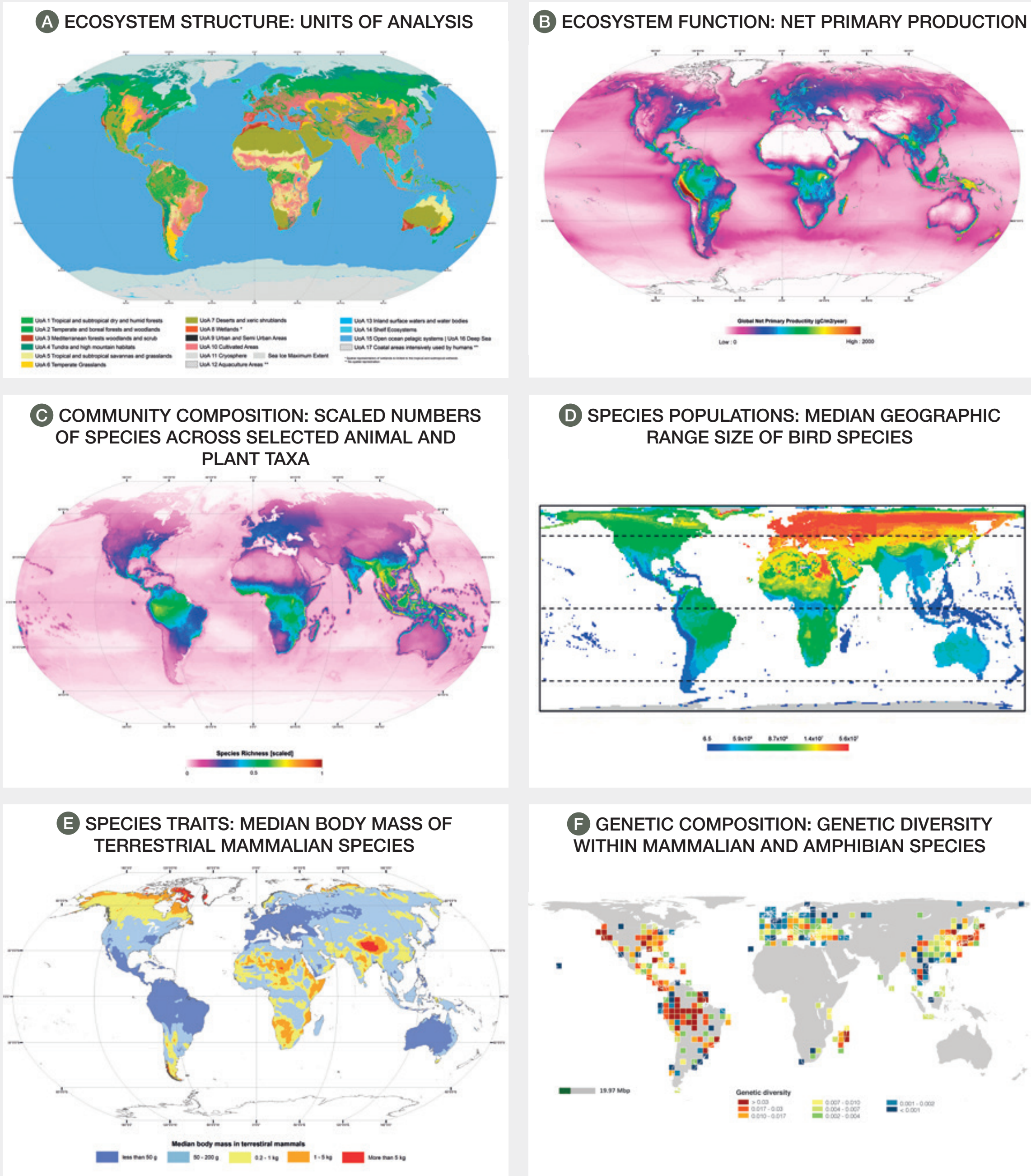


Figure 2 2 2 **Maps of the current distribution of key aspects of nature as measured using the key metrics described in the Essential Biodiversity Variables framework.**

A: **Ecosystem structure** – Extent of natural and anthropogenic units of analysis considered in this assessment. B: **Ecosystem function** – Net primary production (Behrenfeld & Falkowski, 1997; Zhao & Running, 2010). C: **Community composition** – Relative numbers of species per 0.5-degree grid cell, averaged across terrestrial amphibians, reptiles, mammals (data from the IUCN Red List of Threatened Species, https://www.iucnredlist.org/resources/spatial-data-download) and vascular plants (Kreft & Jetz, 2007), freshwater species (data from Collen *et al.*, 2014) and marine species (data from Selig *et al.*, 2014). D: **Species populations** – Median geographic range size of bird species (Orme et al., 2006). E: **Species traits** – median body mass of mammalian species (Santini *et al.*, 2017). F: **Genetic composition** – Average genetic diversity within mammalian and amphibian species within each grid cell (Miraldo *et al.*, 2016).

land-use changes (Kondo *et al.*, 2018; Pan *et al.*, 2011). Between 2000 and 2007, the global forest carbon sink is estimated to have removed 2.4 billion tons of carbon per year from the atmosphere (Pan *et al.*, 2011). Much of this was stored in tropical forests (0.8 billion tons per year), followed by temperate forests (0.8 billion tons per year) and boreal forests (0.5 billion tons per year). Soils are also an important component of terrestrial carbon sinks. For example, 50–70% of the carbon in boreal forests is stored in the soils, particularly in roots and root-associated fungi (Clemmensen *et al.*, 2013). Furthermore, some regions, such as tropical forests and peatlands (e.g., Baccini *et al.*, 2017) are vulnerable to becoming large CO_2 emitters when there is a change in their structure and resulting function (e.g., due to land-use change).

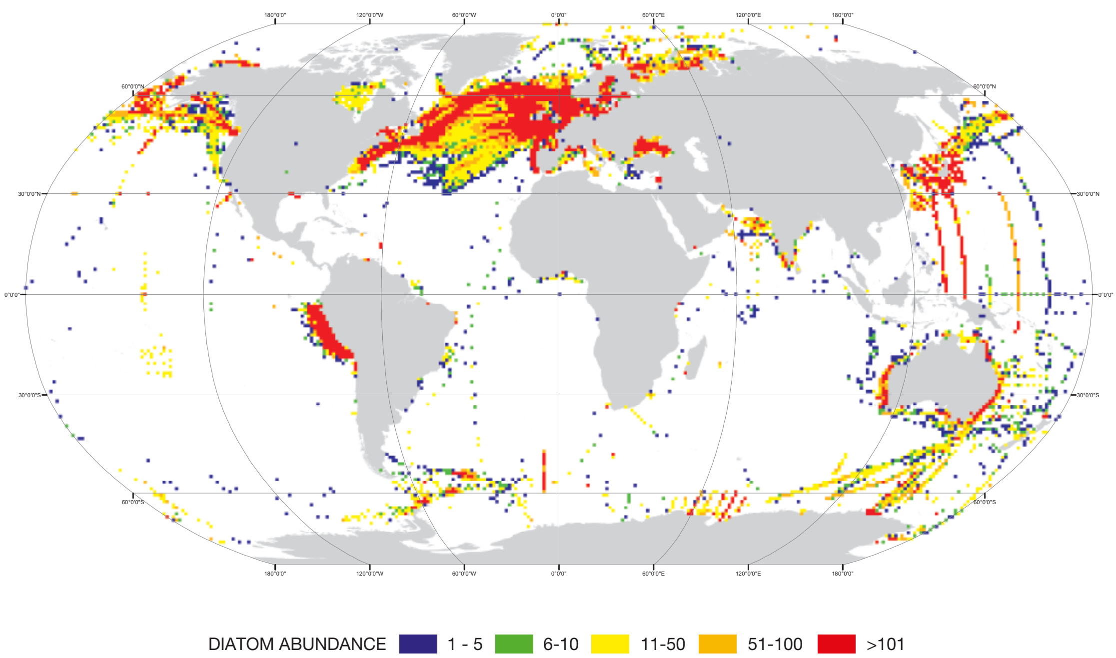
In the ocean, CO_2 is exchanged with the atmosphere primarily by air-sea exchange based on inorganic carbon chemistry. Ocean general circulation, and marine biological processes also affects CO_2 exchange with atmosphere. The CO_2 in the ocean is exported effectively to the deep ocean via the biological pump. Therefore, ocean NPP is one of the most essential factors to determine ocean CO_2 sequestration.

2.2.3.4 Community composition

The term ecological community is used to describe an assemblage of plants, animals and other organisms that are interacting in a unique habitat where their structure, composition and distribution are determined by environmental factors such as soil type, altitude and temperature and water availability. At a global scale there is high variation in the distribution and diversity of different communities, with changes occurring across latitudinal and altitudinal gradients in both terrestrial and ocean environments. Probably one of the most well-known global trends in community composition is the latitudinal gradient in diversity on land, with the highest number of species per unit area at the equator and the lowest at the Poles (e.g., mammals, birds, reptiles, amphibians, and vascular plants; see Willig *et al.*, 2003 for a review). Species interactions also appear to be stronger in the tropics (Schemske *et al.*, 2009). However, some groups show departures from this trend, for example bees and aphids (Kindlmann *et al.*, 2007).

Box 2 2 **Global patterns in composition of marine diatoms (algae).**

Marine plankton communities, including diatoms contribute around 20% of global primary productivity and are hugely significant in biogeochemical cycles and functioning of aquatic food webs (Armbrust, 2009). Until recently little had been known about variations in the diversity and abundance of these communities across the global oceans. A recent global study of diatoms (Malviya *et al.*, 2016) demonstrated that although most species were found at all sites, 10 genera accounted for more than 92% of the samples indicating the dominance of a few types in the world's oceans. Overall the highest abundance of diatoms was found in regions of high productivity (upwelling zones) and the high latitude Southern Oceans.



Global abundance of diatom (Bacillariophyta) species obtained from OBIS datasets (April 2018) each square is coloured according to the abundance of diatoms species observed in the area of 100 sqkm) (from Malviya *et al.,* 2016).

In marine environments, many groups also show a trend of decreasing species richness from the equator to the poles (e.g., fish, tunicates, crustaceans, mollusks, brachiopods, corals, foraminiferans; and see Tittensor *et al.*, 2010), but specific groups or habitats can substantially deviate from this trend (see Willig & Presley, 2018 for a review). For example, baleen whales have their highest diversity at southern subpolar and temperate latitudes (Kaschner *et al.*, 2011). Biodiversity at the seafloor has a maximum at or close to continental margins in areas of high carbon flux (Menot *et al.*, 2010; Woolley *et al.*, 2016).

In addition to these global patterns of diversity and abundance in community composition, there are also a number of well-defined communities of plants and animals associated with geographical isolation (insular systems), endemism (biodiversity hotspots), and diversity of species of plants, crops and microorganisms useful to people (agrobiodiversity hotspots). These areas are home to a disproportionately high proportion of the world's species, including for example the Eastern Arc mountains of Africa (Burgess *et al.*, 2007) and Pacific seamounts (Richer de Forges *et al.*, 2000); the narrow distributions of most of these species makes them intrinsically more susceptible to drivers of change. Many of these areas typically constitute only a small fraction of a biome or IPBES terrestrial and aquatic unit of analysis, raising the risk that their status, trends and projected futures may not be clearly reflected in assessments of nature at those large scales.

A description of each will be briefly discussed in turn.

2.2.3.4.1 Insular systems

An insular environment or "island" is any area of habitat suitable for a specific ecosystem that is surrounded by an expanse of unsuitable habitat. Examples of insular systems include mountain tops, lakes, seamounts, enclosed seas, and isolated islands or reefs. These systems have several important properties that set them apart from non-insular systems and thus dictate their specific consideration in this assessment.

Biotas in insular environments are often depauperate relative to biotas in similar but well-connected environments – because relatively few individuals of relatively few species arrive from across the surrounding unsuitable habitat (Brown & Kodric-Brown, 1977; Vuilleumier, 1970). This limited colonization results in many "empty niches" into which the few colonizing species can diversify, leading to a high proportion of endemic species (e.g., Australia, Keast, 1968; Galapagos, Johnson & Raven, 1973; Madagascar, Wilmé *et al.*, 2006; mountain tops Steinbauer *et al.*, 2016). The result can be a collection of unique species with little or no taxonomic equivalent on the mainland, such as flightless cormorants and marine iguanas in Galapagos or honeycreepers and silverswords in Hawai'i. The limited colonization of islands can also lead to "enemy release," where the few colonists lose their defenses against former competitors, parasites, or predators, including humans. The resulting "evolutionary naïveté" renders many taxa in insular systems especially susceptible to exploitation by humans and to the spread of invasive species, especially predators and diseases (Sih *et al.*, 2010). Examples of the resulting biological catastrophes include the wholesale extinction of birds after the arrival of humans in New Zealand (Bunce *et al.*, 2005, 2009), the arrival of avian malaria in Hawaii (Warner, 1968), and the arrival of brown tree snakes in Guam (Savidge, 1987).

Many of these problems facing insular taxa are compounded when the insular habitats are very small and isolated, including tiny remote Pacific islands, alpine lakes, and dessert oases. In addition to exacerbation of these general problems of insularity, especially small insular systems often have a narrow range of environmental conditions to which local organisms are precisely adapted, along with very limited genetic variability. As a result, changing environmental conditions (e.g., climate warming or invasive alien species) that eliminate suitable habitat can be hard to mitigate through movement or adaptive responses (e.g., Corlett & Westcott, 2013; Courchamp *et al.*, 2014; Vergés *et al.*, 2014). Particularly obvious in this respect is the shrinking habitat of cool-climate organisms existing on mountain-top sky islands surround by unsuitable warm conditions. Finally, the small population sizes typical of species living in small insular habitats can lead to genetic drift and inbreeding that greatly reduce genetic variation in some situations. As insular taxa are often very local, rare, unique, and vulnerable, active and specific conservation efforts are critical. On the one hand, it is particularly important to limit biological invasions, as the effects for insular taxa are often severe and irreversible. On the other hand, insular taxa can often benefit from efforts to increase population sizes through habitat preservation and restoration, and to increase connectivity among isolated populations of a given species.

2.2.3.4.2 Hotspots of endemism and rarity

"Biodiversity hotspot" was a term originally proposed to describe communities of terrestrial plants and animals that contained a high concentration of endemic species yet had lost more than 70% of their original cover due to land-use change (Mittermeier *et al.*, 2011, 2004). There are now 35 terrestrial hotspots that cover only 17.3% of the Earth's terrestrial surface, characterized by both exceptional biodiversity and considerable habitat loss (Marchese, 2015).

In the oceans, the concept of hotspots of endemism is less clear since a high potential for species dispersal and only a few efficient large-scale barriers hamper the development and maintenance of endemism hotspots. However, there are important exceptions from this rule and some hotspots in species richness and endemism exist. For example, the warm-water shallow coral reefs provide the habitat for estimated 8 x 10^5-2 x 10^6 species (Costello *et al.*, 2015; Knowlton *et al.*, 2010) especially in the Indo-Pacific region. They are, together with Indo-Pacific seamounts, vents and seeps, deep cold coral reefs, shelves around New Caledonia, New Zealand, Australia and the Southern Ocean (Kaiser *et al.*, 2011; Ramirez-Llodra *et al.*, 2010), not only hotspots in species richness and functional biodiversity but also in endemism due to spatial isolation from other habitats or differences in environmental conditions. Marine range rarity is most obvious in Indo-Pacific coastal regions and off Mesoamerica (Roberts *et al.*, 2002; Selig *et al.*, 2014). Also, the deep sea is rich in species and habitats (Knowlton *et al.*, 2010), home to a conservatively estimated 5 x 10^5 macrofaunal species (Snelgrove & Smith, 2002).

Marine phylogenetic uniqueness is most obvious in vent and seep communities since not only single species but also larger older groups of related species (such as families) only occur in such habitats (Van Dover *et al.*, 2018). Some of the unique macroorganisms such as the *Riftia*-tubeworms and vesicomyid clams depend on a symbiosis with chemosynthetic bacteria as well as archaea. Most of these marine systems need special attention because they are increasingly impacted by the exploitation of natural and mineral resources by human activities. In addition, such ecosystems are especially vulnerable due to the rarity of species in the sense of small distribution ranges and their narrow tolerance windows as a result of a strong adaptation to their environment conditions.

Determining the distribution of most vulnerable species (i.e., those rare species with a small range distribution and/or ecological tolerance) is also an issue for terrestrial plants and animals. In the hotspots approach described above, which based on total richness of endemics, there tends to be an overrepresentation of wide-ranging species and some of the rarest and most threatened species that are range-restricted are not highlighted. It can therefore be a poor indicator of the most effective areas for targeted species conservation (Jetz & Rahbek, 2002; Margules & Pressey, 2000; Orme *et al.*, 2005). An alternative approach is to use a measure such as range-size rarity (also called "endemism

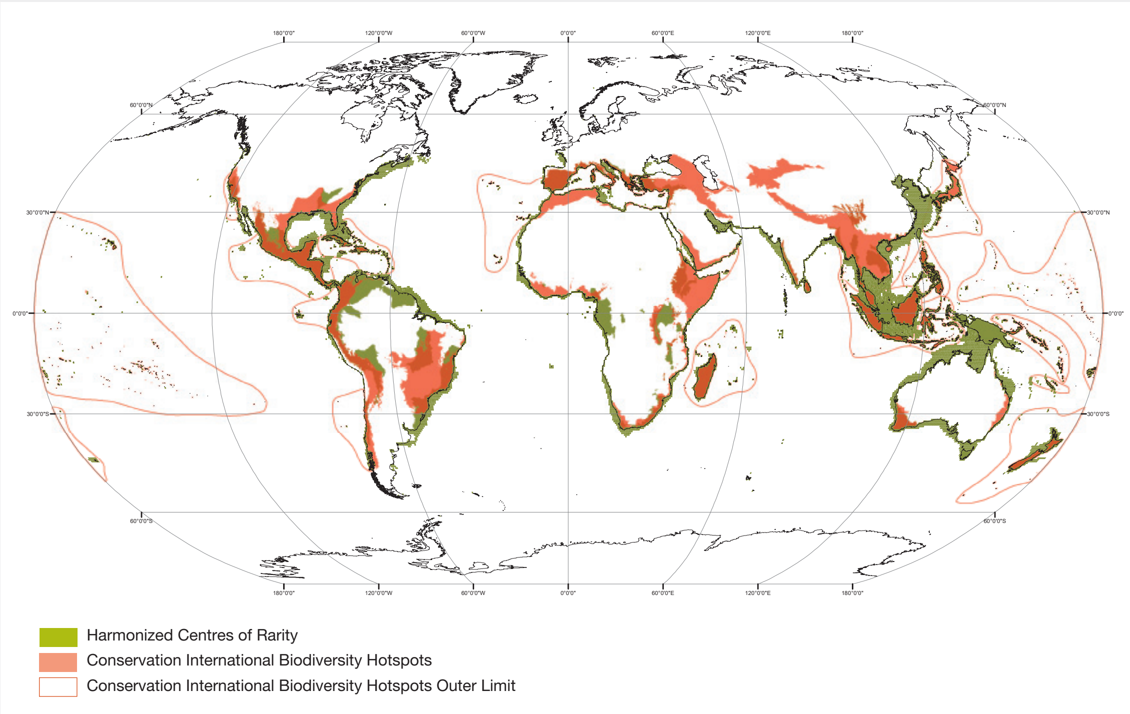


Figure 2 2 3 **Harmonized centres of rarity, representing 7.3% of the land surface and 5% of the marine surface (https://mol.org/patterns/raritycenters; see Supplementary Materials).**

Also indicated are the spatial extent of Conservation International's Biodiversity Hotspots demonstrating large regions where the two measures do not overlap.

richness", or "weighted endemism"; Crisp *et al.*, 2001; Kier & Barthlott, 2001; Williams *et al.*, 1996). In this approach range-size rarity is given as the count of species present in a region, weighted by their respective range proportion inside the region (Moilanen, 2007; Pollock *et al.*, 2017; Veach *et al.*, 2017). Using this approach to determine a set of global centres of endemism richness for vascular plants, terrestrial vertebrates, freshwater fishes and select marine taxa, indicates that harmonized centres of rarity cover 7.3% of the land surface and 5% of the marine surface (**Figure 2.2.3**; for a full description of methodology and details of taxa analysed see Supplementary Materials). Some of the indicators of nature reported below are sufficiently spatially resolved to allow their global status and trends to be compared to the status and trends within these.

2.2.3.4.3 Hotspots of agrobiodiversity

Agrobiodiversity is the defined as "the variety and variability of animals, plants and micro-organisms that are used directly or indirectly for food and agriculture, including crops, livestock, forestry and fisheries. It comprises the diversity of genetic resources (varieties, breeds) and species used for food, fodder, fibre, fuel and pharmaceuticals. It also includes the diversity of non-harvested species that support production (soil micro-organisms, predators, pollinators), and those in the wider environment that support agro-ecosystems (agricultural, pastoral, forest and aquatic) as well as the diversity of the agro-ecosystems" (CBD, 2000). Agrobiodiversity is therefore a vital component of healthy diverse diets and of sustainable systems that provide multiple benefits to people (Biodiversity International, 2017).

Globally a very large number of crop and domestic animal species, landraces, breeds and varieties, together with their wild relatives, contribute to food security (Dulloo *et al.*, 2014; Gepts *et al.*, 2013; Jacobsen *et al.*, 2015). Yet most human food comes from a relatively small number of plants and animals. Of the Earth's estimated 400,000 plant species, two thirds of which are thought to be edible, humans only eat approximately 200 species globally (Warren, 2015), and just four crops (wheat, rice, maize and potato) account for more than 60% of global food energy intake by humans (FAO, 2015b). The primary regions of diversity of major agricultural crops are mostly tropical or subtropical (**Figure 2.2.5**; Khoury *et al.*, 2016), though many of these crops are grown well beyond their areas of origin and maximum diversity; on average, over two thirds of nations' food supplies come from such 'foreign' crops (Khoury *et al.*, 2016). The location and conservation of hotspots of diversity of landraces, breeds and varieties therefore play a critical role in proving a gene pool and

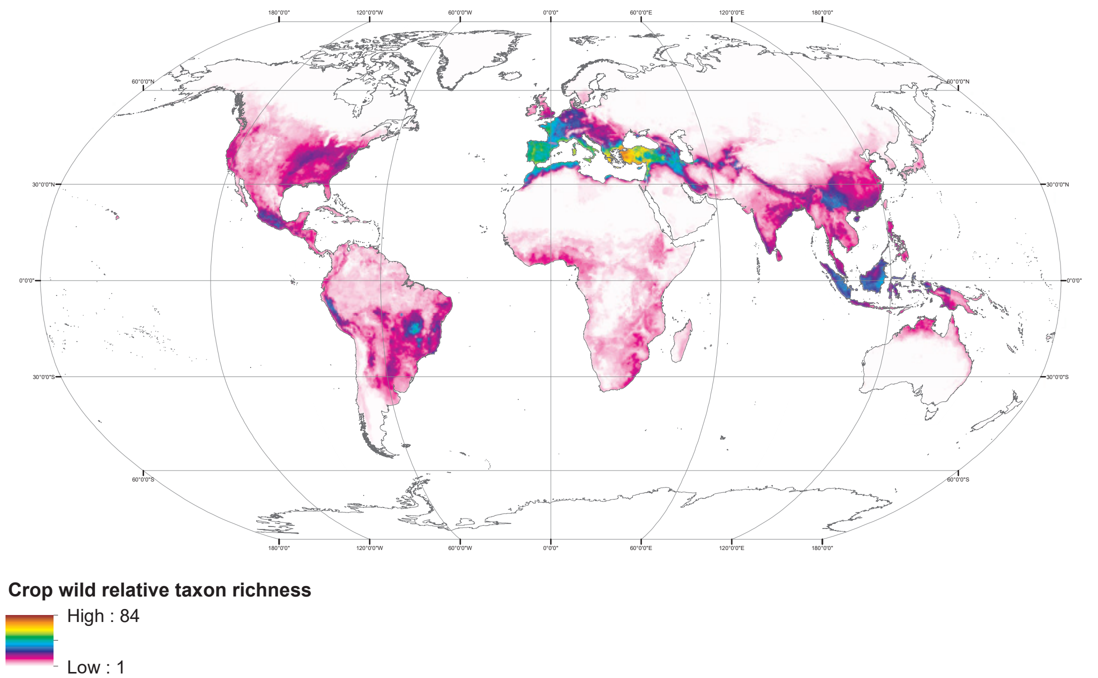


Figure 2 2 4 **Number of crop wild relative species currently known and their global distribution (redrawn from Castañeda-Álvarez *et al.*, 2016).**

variety of traits that may provide resilience against climate change, pests and pathogens (Jacobsen *et al.*, 2015). One branch of agrobiodiversity that has long been recognized in this respect are crop wild relatives (CWR) (Vavilov, 1926). CWRs are the ancestral species or other close evolutionary relatives from which present-day crops evolved, and they are essential to maintaining a pool of genetic variation underpinning our current crops. Their conservation is particularly important given that current crops have heavily depleted gene pools resulting from complex domestication processes, human selection and diffusions of crops and domestic animals, and ongoing diversification (Ellis, 2018; Harlan & de Wet, 1971; Larson & Fuller, 2014; Stépanoff & Vigne, 2018; Vigne *et al.*, 2012; Willcox, 2013; Zohary *et al.*, 2012).

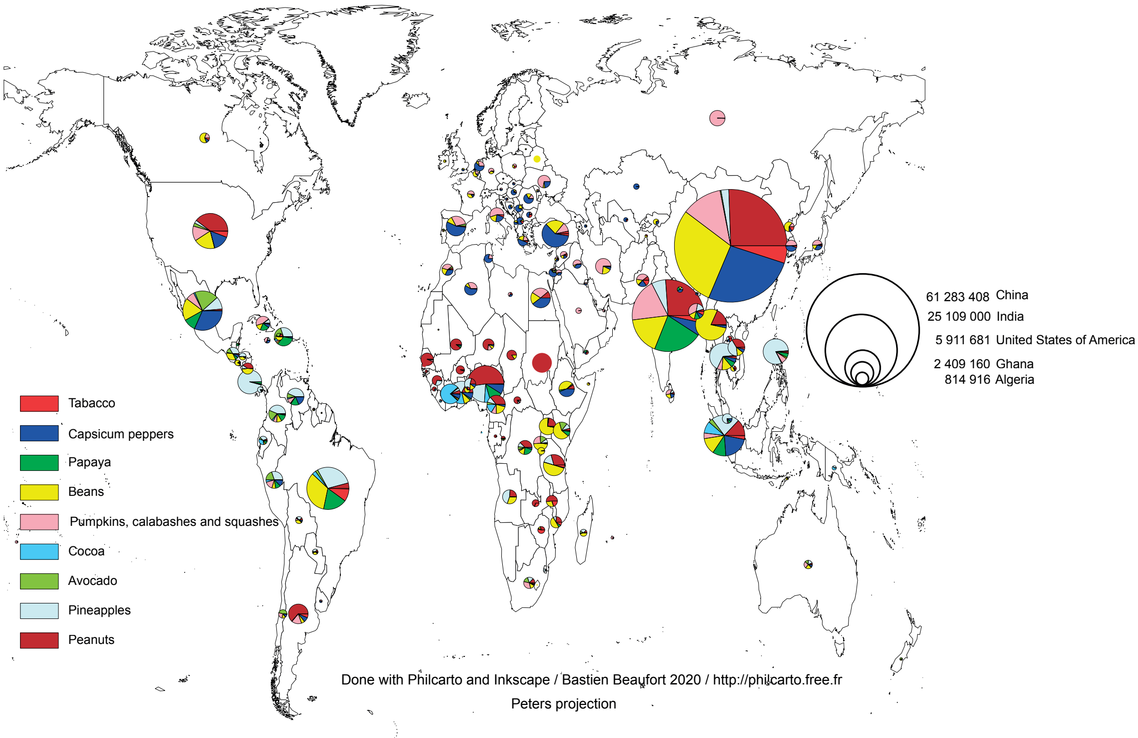
Vavilov (1926) originally recognized eight centres of crop domestication containing high numbers of CWRs. More recent mapping work (e.g., Castañeda-Álvarez *et al.*, 2016; Vincent *et al.*, 2013) suggests that there are many more regions where CWR occur and although the current richness hotspots align with traditionally recognized centres of crop diversity, other regions such as central and western Europe, the eastern USA, South-Eastern Africa and northern Australia also contain high concentrations of richness of CWRs **(Figure 2.2.4)**.

However, not all crop domestication and diversification has taken place near the areas of CWR's origins (Harlan & de Wet, 1971). New genomic tools and morphometric analyses are suggesting that many crops may have multi local areas of origin (e.g., olive and wheat; Terral & Arnold-Simard, 1996; Willcox, 2013) with early diffusions at a wide scale beyond the areas of origin of CWR **(Figure 2.2.5)** (see also Amazonian examples in **Box 2.3**). The same is also true in animal domestication, where complex evolutionary and ecological processes along with human selection have shaped the diversity and distribution of domestic animals (Larson & Fuller, 2014; Larson *et al.*, 2014) with the current distributions being much wider than original centres of origin.

Another large component of agrobiodiversity underpins other material and non-material contributions (fodder, fuel, fibres, etc.); (Diazgranados *et al.*, 2018; SOTWP, 2016); for example, there are at least 28,000 plant species that are currently recorded as being of medicinal use (Allkin *et al.*, 2017). Analysis of the distribution of these categories of plants indicates that the vast majority of them have overlapping and distinctive global ranges (see chapter 3; **Figure 2.2.6**; Allkin & Patmore, 2018; Diazgranados *et al.*, 2018), yet some of the highest concentrations of medicinal plant species appear to occur in regions outside of formally designated biodiversity hotspots.

Figure 2 2 5 **Origins and primary regions of diversity of agricultural crops. Source: Khoury *et al.* (2016).**

Box 2 3 **The contemporary globalization of native Amazonian and American plants.**



This map shows the current global centres of production (in tons) of key crops that originated from native American and Amazonian plants (Beaufort, 2017). Some important Amazonian crops, such as manioc and rubber, are not displayed.

The map highlights that many crops originating from agrobiodiverse regions are now used well beyond their centres of origin and domestication; and that the Amazon – often portrayed as the ultimate example of "pristine forest" – is actually a hugely important centre of domesticated nature, contributing significantly to the global agricultural economy.

One of the most globally widespread domesticated Amazonian plant genera is *Capsicum* (pepper; species *annum*, *chinense*, and *pubescens*). Other examples from the Amazon include pineapple *(Ananas comosus)*, papaya *(Carica papaya)* and peanuts *(Arachis hypogeae)*, which originated in South-West Amazon rainforest. Cocoa is also another globally important plant, which has at least ten different domesticated indigenous varieties scattered across the Amazon rainforest. Many of these cocoa varieties, as with dozens of other varieties of seeds and cultivars, are still managed by local traditional and indigenous groups in the Amazon. (Sources: Beaufort, 2017; FAO, 2014a)

2.2.3.5 Species populations

A measure of the abundance and distribution of a species' population is an important facet of nature to determine because this can significantly influence the level of ecosystem service provision (Luck *et al.*, 2003). For example, in agricultural landscapes where populations of local native vegetation provide important foraging and nesting habitats for pollinators, a distance of <2km between populations can mean that some fields are too far from nests to receive pollinator visits thus significantly reducing pollination services (Luck *et al.*, 2003; Nogué *et al.*, 2016). It is also an important measure to understand because species with naturally small ranges and populations tend to be more vulnerable to extinction, and the fact that a species, before going extinct, goes through a strong reduction in population size; and because sometimes range is often used as a measure of extinction risk (see Section 2.2.4).

The great majority of animal and plant species have small geographic distributions, many being found only across a very small proportion of the world's surface (e.g., **Figure 2.2.2D**; Orme *et al.*, 2006)). Species also differ in the population density (numbers per unit area or volume). This can be because of ecological and life history factors such as fecundity, trophic level and body size. For example, larger species tend to be less abundant locally, regionally and globally (White *et al.*, 2007). Population sizes of all species can also fluctuate naturally over time and space in response to natural changes in the abiotic environment and species interactions (e.g., Chisholm *et al.*, 2014; Inchausti & Halley, 2001): as a general rule, species' abundance will tend to be

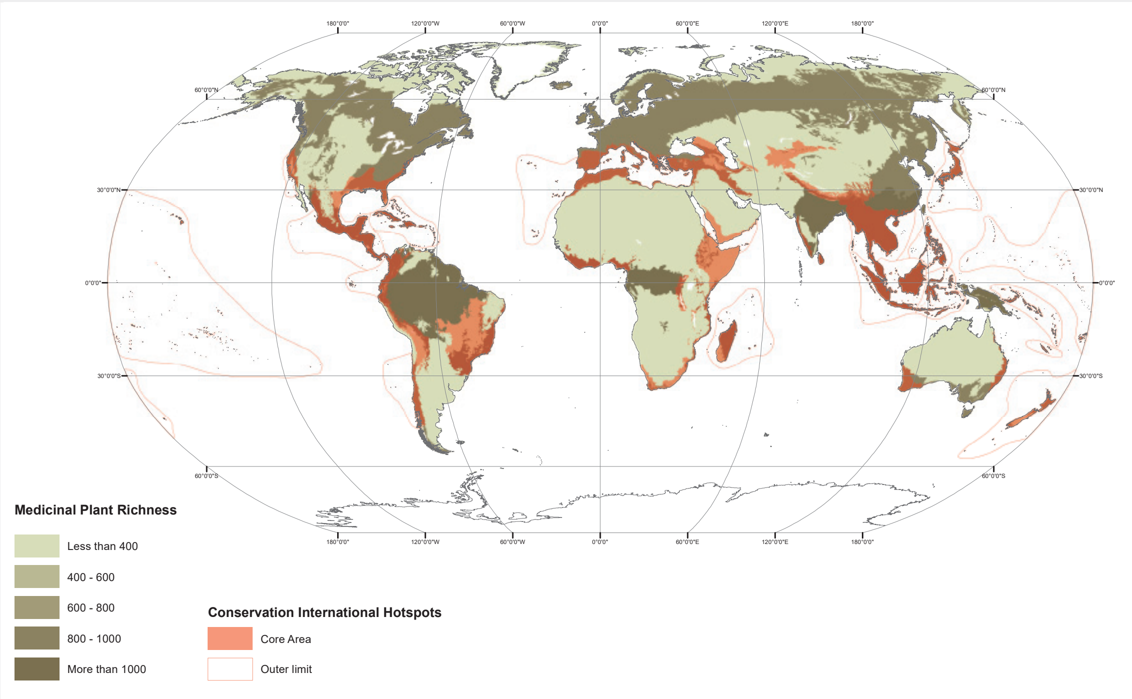


Figure 2 2 6 **Mean medicinal plant species (per 2° grid cell) in each natural unit of analysis (Allkin *et al.*, 2017; Diazgranados *et al.*, 2018).**

Also indicated are Conservation International's biodiversity hotspots. Acknowledgement and Source of map: Samuel Pironon and Ian Ondo, Department of Biodiversity Informatics and Spatial Analysis, Kew, Royal Botanic Gardens.

higher at places and times with more resources and fewer natural enemies. This is particularly true on the deep sea floor where abundances tend to be low even though species richness is high (Ramirez-Llodra *et al.*, 2010).

2.2.3.6 Organismal traits

Traits refer to the structural, chemical and physiological characteristics of plants and animals (e.g., body size, clutch size, plant height, wood density, leaf size or nutrient content, rooting-depth) that are related to the uptake, use and allocation of resources. Global variations in traits reflect the combined influence of abiotic (climate, geology, soils) and biotic variables (**Figure 2.2.2E**; Simard *et al.*, 2011) and can often mediate the relationship between organisms and their environment, thus dictating the resilience of biodiversity to environmental change (Willis *et al.*, 2018). Many traits show consistent patterns of within-species geographic variation; for example, most mammalian and avian species show larger body size in cooler regions (Meiri & Dayan, 2003; Olsen *et al.*, 2009). Similarly, leaf area and plant height become reduced in cooler regions. An understanding of traits is important for both biodiversity conservation and determining NCP.

First, traits directly affect the ability or otherwise of plants and animals to respond to environmental perturbations including land-use change, climate change, pests and pathogens and this in turn directly affects their conservation potential. When a community of organisms faces a particular driver of change, its responses will be therefore strongly mediated by the set of traits in the community and how variation in those traits is distributed within and among species and populations (e.g., Díaz *et al.*, 2013; Hevia *et al.*, 2017; Suding *et al.*, 2008). For example, in a global assessment on plant traits (Willis *et al.*, 2018), species with a less dense wood and shorter roots were less able to withstand intervals of drought than those possessing these traits. The same is also true for animals. In a recent study on global terrestrial mammals, for example, those species not possessing traits adapted to burrowing and/or requiring a specialized diet were less resilient to climate change (Pacifici *et al.*, 2017). There are also similar studies of traits of marine organisms to again indicate that certain traits provide greater resilience to environmental change (Costello *et al.*, 2015).

Second, organismal traits provide a critical link to biological functions that underpin the delivery of many important societal benefits (De Bello *et al.*, 2010; Diaz *et al.*, 2006; Lavorel, 2013). These include food and timber (quality and yield), pollination services, carbon sequestration, and soil nutrient quality and retention (De Bello *et al.*, 2010). Understanding variation in traits which enable resource security and supply particularly in the face of environmental change will become increasingly important in the future (Willis *et al.*, 2018). Yet despite their importance, still very little is known about the global distribution of traits in most taxonomic groups; e.g., a recent estimate suggested that only 2% of documented terrestrial plant species have associated trait measurements (Jetz *et al.*, 2016).

2.2.3.7 Genetic composition

Diversity in genotypes within and between species ultimately underpins variation among plants and animals, wild and domesticated, and thus provides the essential building blocks that underpin NCP. A diverse gene pool is also critical to provide resilience to disease, climate change and other environmental perturbations both in wild and domesticated populations. Understanding the diversity and distribution of global genetic resources is therefore of critical importance and has been identified as one of the most essential biodiversity variables to monitor in order to understand the health of the planet (Steffen *et al.*, 2015b).

Factors responsible for global patterns of genetic diversity are complex and are the result of evolutionary and ecological processes occurring across multiple timescales (Schluter & Pennell, 2017). However, some generalized patterns are apparent in animals. For example, a recent study that examined genetic diversity within 4600 mammalian and amphibian species at a global scale, demonstrated a broad latitudinal gradient with higher values in the tropical Andes and Amazonia (**Figure 2.2.2F**; Miraldo *et al.*, 2016). Other regions with high genetic diversity include the subtropical parts of South Africa for mammals and the eastern coast of Japan for amphibians. In temperate regions, western North America contains high level of genetic diversity, coinciding with high levels of mammalian species richness. In another recent study, examining genetic diversity of 76 animal species with global distributions, species traits related to parental investment and reproductive rates were also found to significantly influence genetic diversity – short-lived generalist species with high reproductive rates tend to have much higher levels of genetic diversity. Thus slow-living specialists have a much lower genetic diversity and are possibly therefore more vulnerable to environmental perturbations (Romiguier *et al.*, 2014).

A global understanding of patterns of genetic diversity in other groups (e.g., plants, marine organisms) is largely lacking although there are many excellent regional-scale studies indicating complex patterns resulting from processes occurring over millions of years (see Schluter & Pennell, 2017 for a review) and gene pools associated with crop wild relatives (see above).

Policy decisions can be tailored to enhancing adaptive evolution of species that are beneficial (e.g., keystone species or species with important benefits to people) and reducing the adaptive evolution of species that are detrimental (e.g., pests, pathogens, weeds). This topic is discussed in **Box 2.6** (Rapid evolution) in section 2.2.5.2.5.

2.2.4 CONTRIBUTION OF INDIGENOUS PEOPLES AND LOCAL COMMUNITIES TO THE CO-PRODUCTION AND MAINTENANCE OF NATURE

Indigenous Peoples and Local Communities (IPLCs), whose customary land encompasses approximately 50% of the global land area (Oxfam *et al.*, 2016) but see problems of mapping in chapter 1), often consider humans as an element of nature, with reciprocal exchanges between humans and non-humans that lead to nurturing and co-production.

It is important to emphasize that what has often been traditionally seen from a scientific or romantic perspective as untouched nature or wilderness is often the product of long-term use by IPLCs (e.g., the Kayapo cultural forests; Fairhead *et al.*, 1996; Posey, 1985; Willis & Birks, 2006). As wilderness areas cover an estimated 23% of land and are core to nature conservation (Watson *et al.*, 2016), a careful re-examination of cases based on long-term paleoecological and human historical records may help to overcome this controversy.

Although global studies that compare the status of biodiversity inside versus outside IPLC areas are limited, a large fraction of terrestrial biodiversity is found on IPLC land" (Sobrevila, 2008; Garnett *et al.*, 2018; Gorenflo *et al.*, 2012). Whilst this figure remains an estimate until there is a more complete documentation of areas managed and/or held by IPLCs (through efforts such as the Global Registry of ICCAs) and increased inclusion of diverse governance types in the World Database on Protected Areas (Corrigan *et al.*, 2016). However, such a high estimate is not unrealistic, given that at least a quarter of the global land area is traditionally owned, managed, used or occupied by Indigenous Peoples, including approximately 35 per cent of the area that is formally protected and approximately 35 per cent of all remaining terrestrial areas with very low human intervention (Garnett *et al.*, 2018; see also http://www.landmarkmap.org/ and chapter 1); and assuming that most rural populations pursuing small-scale non-industrial agriculture and forest management belong to 'local communities' adapted to local conditions.

It has also been noted many times that global patterns of biological diversity and cultural diversity seem not to be independent. However, while the overlap between cultural (e.g., linguistic) and biological diversity at the global scale is undeniable (Maffi, 2001; Stepp *et al.*, 2004), likely reasons for co-occurrence of linguistic and biological diversity are complex and less well known (Moore *et al.*, 2002). Co-occurrences may be due, for example, by the longevity of local occupation, isolation caused by terrain, and specific (e.g., tribal) social structures and appear to vary among localities. Nevertheless, strong geographic concordance argues for some form of functional connection (Gorenflo *et al.*, 2012); this is something that requires further biocultural explorations (see Section 2.2.6.3 for more details; Gavin *et al.*, 2015).

There are many cases in the world where IPLCs 'contribute' to nature by co-producing genetic diversity, species and ecosystem diversity through 'accompanying' natural processes with anthropogenic assets (knowledge, practices, technology; Berkes, 2012; Forest Peoples Programme *et al.*, 2016b; Posey, 1999). IPLCs often manage inland and coastal areas based on culturally specific values and worldviews, applying principles and indicators like health of the land, caring for the country, and reciprocal responsibility with the goal of promoting ecosystem health, respect and integrity (Berkes, 2012; Lyver *et al.*, 2017; Posey, 1999). However, unsustainable indigenous practices are becoming increasingly common, e.g., the 'empty', 'silent' forests (Redford, 1992) and pasture degradation (see also 2.2.5.1-2-3, chapter 3 (3.2.4, 3.3.3) and chapter 4 (4.4.1)). Changes in these areas are also often driven by changes in land management by governments and corporations (White *et al.*, 2012), and the proportion of areas still managed by IPLCs and/or according to indigenous and local concepts is decreasing (Borras Jr *et al.*, 2011).

Case studies below show where the nature that contributes to people has been co-produced by local people.

2.2.4.1 Co-production of cultural landscapes with high ecosystem heterogeneity

High-diversity cultural landscapes (Agnoletti, 2006) and Socio-Ecological Production Landscapes and Seascapes (SEPLS, satoyama-initiative.org), which often comprise a complex mosaic of forested areas, wet, irrigated and dry places, and coastal habitats, can provide a richness of food, fodder, timber, medicinal plants to local communities. Such landscapes have a long history of human-nature co-production. For example, the Mediterranean pasture or crop and oak agro-sylvo-pastoral systems (known as Dehesa in Spain, Montado in Portugal), olive and fig agro-sylvo-pastoral systems, holm oak-truffle woods, chestnut rural forests, and argan agroecosystems are a number of human-nature co-production systems that are known to host a rich open habitat flora with diverse ecotones and a high level of landscape heterogeneity (Aumeeruddy-Thomas *et al.*, 2016, 2012; García-Tejero & Taboada, 2016; Lopez-Sanchez *et al.*, 2016; Michon, 2011).

2.2.4.2 Development of species-rich semi-natural ecosystems of wild species

In cultural landscapes where people have actively changed the local disturbance regime, species-rich habitats can develop. Some of these ecosystems, made up of wild native species, became local 'hotspots' of diversity. These include for example, the European hay meadows (see **Box 2.4** below) which have replaced many broad-leaved and coniferous forests in mountainous and boreal regions, and which were purposefully developed by local communities (Babai & Molnár, 2014). These meadows are among the most species-rich grasslands on Earth at several small spatial scales (up to 60–80 vascular plant species per 16 m^2; Wilson *et al.*, 2012). The species richness of these hay meadows is correlated with the longevity and continuity of a more or less stable extensive traditional management spanning thousands of years (Merunková & Chytrý, 2012; Reitalu *et al.*, 2010; Zobel & Kont, 1992).

2.2.4.3 Creation of new ecosystems with a combination of wild and domestic species

In many regions of the world Indigenous Peoples and Local Communities have combined wild and domesticated species in their agroecosystems to create new, often highly diverse ecosystems. These farming systems often sustain communities of diverse plant and animal species with increased synergy (in production and resilience). For example, IPLCs have developed multi-species tropical forest gardens in Kebu-talun and Pekarangan in West Java (Christanty *et al.*, 1986), rotational swidden agriculture in Thailand (Wangpakapattanawong *et al.*, 2010) and see **Box 2.4** below). In many of these locally developed traditional agroforestry systems trees, crops and/or livestock associations (Michon *et al.*, 2000; Wiersum, 2004) differ according to biocultural, social, economic and political contexts. In addition, the interaction between wild and cultivated components (often called rural forests) that occur in this agroforestry systems can result in hybridization and have been suggested as a major driver of tree domestication across the planet (Aumeeruddy-Thomas & Michon, 2018; Aumeeruddy-Thomas, 1994; Genin *et al.*, 2013; Michon, 2015).

In wetland ecosystems, another combination of wild and domestic species that occurs is the rice-fish-duck culture in China (Xue *et al.*, 2012). In addition, flooded plains across the tropics (e.g., since pre-Columbian times in Bolivia and French Guyana, also contemporary Africa) have agroecosystems based on the construction of large human-made mounds for cultivation. These are known to have brought into these flooded plains a rich agricultural biodiversity, while hosting also a large diversity of soil diversity and insects that benefit from these elevated terrestrial parts of the landscapes (McKey *et al.*, 2016). Human-made oases or other highly modified ecosystems developed by local communities, can enhance natural processes as well as biological diversity (Tengberg *et al.*, 2013).

2.2.4.4 Contributing to agrodiversity by selection and domestication

Domestication is an ongoing process that has been occurring for at least the past 20,000 years on Earth. Indigenous Peoples and Local Communities maintain many local varieties and breeds of plants, animals, and fungi and thus facilitate adaptations to the changing social-ecological environment. Domestication is about selection of specific traits, and their integration into social-ecological niches that often differ from their original habitats. This process has occurred over millennia, since the Epipaleolithic (ca. 20 000–5 000 years ago) in the Mediterranean region and at similar periods in Papua New Guinea, Mexico, South America, and Central Asia (Castañeda-Álvarez *et al.*, 2016; Ellis *et al.*, 2018; Larson & Fuller, 2014).

Local plant and animal landraces (domesticated, locally adapted, traditional varieties and breeds) may either correspond to areas of origin or be a consequence of human-assisted dispersal across the planet. For instance, the pre-Columbian travel of sweet potato from South America where it was domesticated to the Pacific islands (Roullier *et al.*, 2013a, 2013b), ultimately reached Papua New Guinea where it became a very important staple food and also diversified as a result of isolation from its area of origin, new ecological conditions and selection by humans (see **Box 2.3**). This effect of diffusion and genetic isolation, adaptation and selection are clearly a co-production resulting from Indigenous Peoples and Local Communities manipulating ecological and biological evolutionary processes. Domestic animals have evolved far from their wild relatives' origin and represent another example of joint production linked to selection by people and adaptation to local environments. For example, there is an estimated ca. 800 local breeds of domesticated cattle, although the true numbers are incompletely known (FAO, 2015b).

2.2.4.5 Enhancement of the natural resilience through traditional management

Many traditional resource management systems are 'designed' to be resilient by IPLCs, thus enabling social-ecological systems to collectively respond or adapt to changes (Berkes *et al.*, 1998). Activities that are promoted to enhance natural resilience include for example, the

Box 2 4 Two cultural landscapes where anthropogenic processes enhance biodiversity.

Embedded in the cultural landscape in Gyimes (Carpathians, Romania), these meadows were created by local Hungarian Csángó people to provide valuable hay and are now extremely species-rich semi-natural ecosystems (Section 2.2.4.2). Meadows are managed based on a deep understanding of local ecological processes (e.g., hayseed is gathered in the barns and spread onto hay meadows to increase hay quantity and quality, (Babai *et al.*, 2014, 2015). (Photo: Dániel Babai)

This socioecological production landscape has created new ecosystems with many wild and domestic species (Section 2.2.4.3), with rotational farming developed and managed by Karen people in Thailand with traditional co-creation techniques (an example for 2.2.4.3). *"A system that speaks to sustainability and livelihood security". "We select places for cultivation by listening to the sound of a stick hit to the soil in soft-wood and bamboo forests able to resprout while we avoid areas with large trees, having certain birds and mammals, and that are close to streams." "We seed not only rice but many kinds of vegetables and vibrant coloured flowers believed to keep insects and birds away."* Source: Global Assessment face-to-face consultation with Kriengkrai Chechuang, Thailand. (Photo: Pernilla Malmer)

protection and restoration of natural and modified ecosystems, the sustainable use of soil and water resources, agro-forestry, diversification of farming systems, crop development (e.g., stress-tolerant crops) and various adjustments in cultivation practices (Barrios *et al.*, 2012; Emperaire, 2017; Mijatović *et al.*, 2012). Farmers often utilize the diverse ecology of different crops to add synergy (such as nitrogen fixing plants, trees for shade, animals for fertilizing soils or rice fields). Such systems can diffuse risks caused by extreme climate events (e.g., floods, drought), pests or pathogens. Traditional knowledge of the ecology and cultivation of crops is combined with social practices, such as exchange networks, including seed exchange networks (Coomes *et al.*, 2015; Thomas & Caillon, 2016; Wencélius *et al.*, 2016) to increase a farmers' capacity to find adequate landraces either to adapt to changing markets or changing climate.

2.2.4.6 Increase local net primary biomass production at the landscape scale

IPLCs often increase local biomass production by, for example, rotational farming and disturbance regimes (see Section 2.2.4.2 above). Examples of this type of activity includes for example, creation of rich berry patches (dominated by *Vaccinium* spp. and other berries) in boreal forests by regular burning (Davidson-Hunt, 2003; Johnson, 1994). In addition, prescribed regular burnings and community-based fire management of dry grasslands, forests and marshes can sometimes not only prevent larger fires that would damage local livelihoods, but they can also help the resprouting of herbaceous vegetation and restore habitat and landscape structure favourable for biodiversity (Miller & Davidson-Hunt, 2010; Pellatt & Gedalof, 2014; Russell-Smith *et al.*, 2009). The same is true for some properly executed grazing regimes by domestic livestock that are adapted to the local environment and are able to prevent overgrazing (Molnár, 2014; Tyler *et al.*, 2007).

In other cases, Indigenous Peoples and Local Communities – unintentionally – maintain high levels of prey animals (e.g., sheep) that 'provide' an additional food source, which in turn are important for maintaining iconic predators (lion, leopard, wolf, bear; Casimir, 2001; Mertens & Promberger, 2001). Similarly, fruit gardens 'provide' food for frugivorous mammals when forest fruits are scarce (Moore *et al.*, 2016) and thus contribute to the protection of threatened species by this extra food (Siebert & Belsky, 2014).

2.2.4.7 Contribution to biodiversity by sustaining and protecting ecosystems of high conservation value from external users

IPLCs sustain naturally developed or modified ecosystems (such as the ones featured in the previous sections), and prevent species and ecosystem loss in these areas, for example by restricting access, and thus preventing unsustainable practices by outsider users (e.g., legal and illegal logging, mining, poaching, overexploitation of fisheries; see ICCAs, OECMs; Berkes, 2003; Borrini-Feyerabend *et al.*, 2004; Corrigan *et al.*, 2016; Govan, 2016; Nepstad *et al.*, 2006; also see chapters 3 and 6).

Additionally, some threatened species and some areas have strong cultural and/or spiritual significance (sacred species and sites) or are important for communities' well-being (e.g., medicinal plants, mental health) and thus have been actively conserved by communities through totem restrictions, hunting and harvesting taboos, sacred groves, rivers and springs, total or temporal use restrictions or nurturing sources of ecosystem renewal (Bhagwat, 2012; Colding & Folke, 1997; Pungetti *et al.*, 2012). These social taboos are often 'invisible' and thus not recognized or accounted for in conventional conservation (Colding & Folke, 2001) though this is changing (Bennett *et al.*, 2017).

2.2.5 STATUS AND TRENDS IN NATURE

Nature has faced multiple drivers of change from human actions. Many of these drivers have accelerated rapidly (chapter 2.1). The same is true for many changes in nature. Indeed, for some facets of nature, the changes have accelerated so rapidly that as much as half the total anthropogenic change in the whole of human history may have taken place since the mid-20th century. This section first discusses pre-1970 trends in nature before discussing trends since 1970 alongside current status.

2.2.5.1 Pre-1970 trends in nature

Humanity developed the capacity for significant ecosystem engineering around 10,000 years ago, marking a major ecological transition in Earth's history. Since then, the cumulative effects of human activities on some aspects of nature have been dramatic (Boivin *et al.*, 2016; Erlandson & Braje, 2013; Smith & Zeder, 2013). Actions that increased the number of people the land can support have also caused species extinctions and changed species distributions, habitats and landscapes since the Stone Ages (Foley *et al.*, 2013; Pimm & Raven, 2000; Vitousek *et al.*, 1997).

Although the state of nature has changed constantly throughout Earth history, the scale and extent of changes

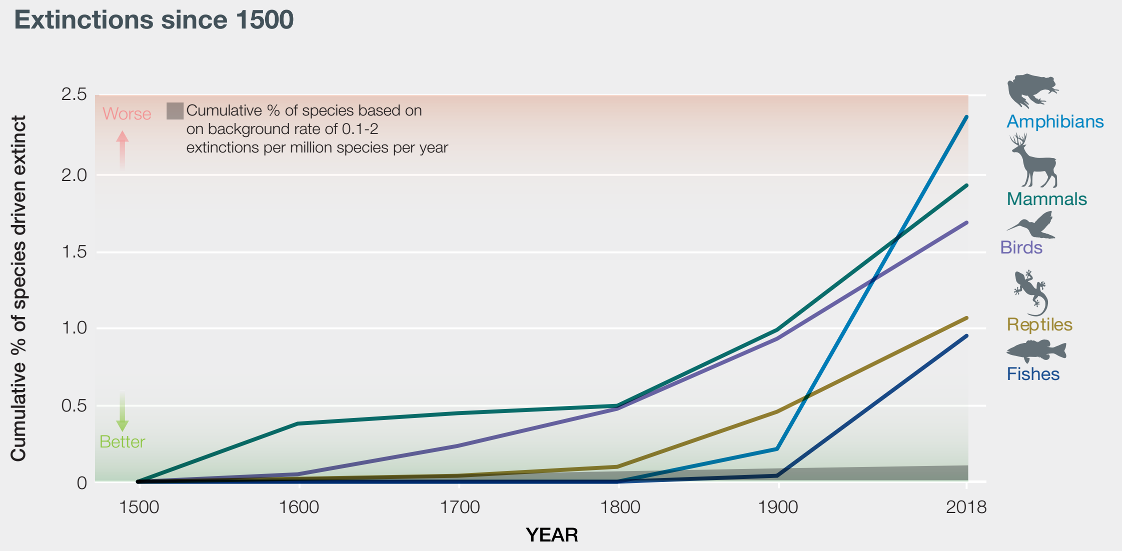


Figure 2 2 7 **Extinction rates per century since 1500 for vertebrate classes.**

Fishes includes bony fishes, cartilaginous fishes and lampreys. Values for Reptiles and Fishes are likely to be underestimates as not all species in these groups have been assessed for the IUCN Red List. The range of background rates of extinction (grey line) is based on 0.1- 2 extinctions per million species per year, following Ceballos et al. (2015) and references therein.
Source: Analysis of data in the IUCN Red List in September 2018.

driven by human actions have led to this human-dominated period in Earth history being commonly called the Anthropocene (Crutzen, 2002). From an ecological perspective, the Anthropocene may have begun in the late Pleistocene (Lyons *et al.*, 2016; Smith & Zeder, 2013). Human actions played a role (along with climate and other drivers) in the megafaunal extinction around the Pleistocene-Holocene boundary (Erlandson & Braje, 2013; Johnson *et al.*, 2017); this disappearance of large herbivores and predators dramatically affected ecosystem structure, fire regimes, seed dispersal, land surface albedo and nutrient availability (Johnson, 2002).

From the Late Pleistocene onwards, humans started to colonize and transformed most resource-rich landscapes on Earth (Erlandson & Braje, 2013). This near-global human expansion was followed by the Neolithic spread of agriculture across the world the centres of domestication (Section 2.2.3.4.3), driven by a set of long-term, complex and independent factors like demography, climate, human behaviour and resource imbalance (Zeder & Smith, 2009). This transformation to agriculture created highly modified production landscapes, caused significant land cover change (e.g., forest loss which triggered erosion and sedimentation in rivers and lakes), and spread new varieties and breeds of domesticated animals and crops as well as other (e.g., weed) species (Baker, 1991). These changes altered all Earth systems from the lithosphere and biosphere to the atmosphere. For example, expansion of paddy rice fields and pastoralism is thought to have increased atmospheric methane from as early as 4000 years ago (Fuller *et al.*, 2011).

All these changes increasingly concentrated biomass into human-favoured species (Barnosky, 2008; Williams *et al.*, 2015). Humans used fire for large-scale transformation of "savannas" (Archibald *et al.*, 2012), while diverse grazing regimes reshaped and expanded grasslands during the last 3000–7000 years. Improved seafaring since the mid-Holocene enabled colonization of even remote islands. Island ecosystems, with "naïve" species and low functional redundancy, often changed dramatically after human colonization (Rick *et al.*, 2013); e.g., two third of bird species native to Pacific islands went extinct between initial human colonization (after 1300 BC) and European contact (17th century) (Duncan *et al.*, 2013). Many exploited species worldwide have evolved to be smaller (Fitzpatrick & Keegan, 2007; Jørgensen *et al.*, 2007).

European colonialism from 1500 to early 1800s fundamentally transformed pre-existing indigenous cultural landscapes, with deforestation for monocrop plantations and the spread of invasive alien species (Dyer *et al.*, 2017). Populations of fur animals, fishes and whales were overexploited for the new global market (Lightfoot *et al.*, 2013; Monsarrat *et al.*, 2016; Rodrigues *et al.*, 2018).

Spread of global commerce mostly from Europe, together with the spread of the European naturalistic worldview, had a huge impact on local human-nature relations and hence on land use (Lightfoot *et al.*, 2013), resulting for example in the spread of timber-oriented forest management (Agnoletti, 2006). Global forest cover decreased for millennia (Pongratz *et al.*, 2008), and large trees were lost from many areas well before the mid-20th century (Lindenmayer *et al.*, 2012; Rackham, 2000).

Marine defaunation started only a few hundred years ago and may have been less severe than defaunation on land (Dirzo *et al.*, 2014; McCauley *et al.*, 2015). Though few marine species are known to have gone globally extinct (Webb & Mindel, 2015), many became ecologically or commercially extinct with the onset of commercial and industrial scale exploitation, the most threatened animals being those that directly interact with land (McCauley *et al.*, 2015).

The Industrial Revolution in Europe, and the growth of populations and cities that it enabled, accelerated impacts on biodiversity. For example, some habitats have lost >90% of their area since 1800 especially in Europe (Biró *et al.*, 2018) and North America. The Green Revolution after World War II drove further agricultural intensification, causing a rapid decline of species of agricultural habitats and the spread of invasive species, and further increasing the proportion of net primary production taken by humanity (Krausmann *et al.*, 2013). Extinction rates rose sharply in the 20th century for all taxonomic groups for which a robust assessment can be made **(Figure 2.2.7)**.

2.2.5.2 Trends in nature since 1970 and current status

The status and recent trends seen in terrestrial, freshwater and marine ecosystems clearly show that humanity is a dominant global influence on nature. This assessment of current status and trends since 1970 synthesizes over 50 quantitative global indicators, covering an unprecedentedly diverse set of facets of nature (because nature is too complex for its trends and status to be captured by one or a few indicators: Section 2.2.3), together with recent meta-analyses, reviews and case studies, organized into Essential Biodiversity Variable classes (Section 2.2.3.1). Attribution of changes to drivers is considered in Section 2.2.6. below.

The linkages among different aspects of nature in ecosystems mean that trends may differ systematically among EBV classes. For instance, forest loss causes local extinction of forest-adapted species, but this species may accelerate once the fraction of natural habitat remaining goes below 30% (Banks-Leite *et al.*, 2014; Ochoa-Quintero *et al.*, 2015). Likewise, local declines in species richness can drive nonlinear declines in ecosystem function, with function initially declining less rapidly than species richness (Cardinale *et al.*, 2012; Hooper *et al.*, 2012).

Even within an EBV class, indicator trends are likely to vary by much more than their statistical margins of error. One reason is that some components of nature are expected to be more sensitive than others – e.g., habitats such as warm-water coral reefs that have narrow environmental tolerances – so indicators reporting on them may show the steepest trends; they are in effect the 'canaries in the coal mine' that provide the first clear evidence that drivers are reshaping nature. By contrast, other indicators try to reflect the status of nature more broadly, e.g., all species within a large taxonomic group such as mammals; these indicators are also important because the broader state of nature underpins consistent delivery of many NCP, especially over longer time scales, across larger areas, and in the face of ongoing drivers (Cardinale *et al.*, 2012; Mace *et al.*, 2012; Oliver *et al.*, 2015; Steffen *et al.*, 2015b; Winfree *et al.*, 2018). A second reason for variation is that some indicators use more coarse-grained data than others. For example, species' extinction risk is measured on a relatively coarse spatial and temporal scale (the IUCN Red List categories), so indicators synthesizing these data may miss gradual declines of abundant, widespread species, which indicators based on species' abundances may capture (Butchart *et al.*, 2005). Consequently, indicators of species populations based on species' extinctions and extinction risk are here considered separately from those based on species' abundances or distributions. A third reason is that some trends might only be apparent at one spatial scale. Because this is particularly true for community composition (Jarzyna & Jetz, 2018; McGill *et al.*, 2015), trends within this EBV class are discussed at three different scales: local (e.g., the set of species in a small area of the same habitat type), regional (e.g., the set of species in a country or large grid cell), and the differences between local communities within the same region.

Where possible, each indicator is expressed in two ways. First, the recent rate of change shows how quickly it is changing over time; the average per decade change in the indicator is expressed as a percentage of the estimated value for 1970 (or, if later, for the beginning of the time-series). Second, the current status is shown as a percentage of the inferred or estimated natural baseline level (i.e., the value in a pristine or at least much less impacted – e.g., pre-industrial – world), showing how much remains (see **Figures 2.2.8–2.2.20**). Most indicators are designed such that a larger value equates to there being more of the focal component of nature, but some are the other way around (e.g., numbers of species extinctions). Here, for ease of comparisons, such reverse indicators are rescaled so that values are larger when there is more nature (note that more is not always better – for instance, a rise in the number of invasive alien species is not desired).

For some indicators that can be mapped at sufficient spatial resolution, the status and trend are also shown within the hotspots of narrowly-distributed species (mapped in **Figure 2.2.3**), and within the areas mapped (Garnett *et al.*, 2018) as indigenous lands (mapped in Figure SPM5); in the plots below, these have "hotspots" or "indigenous lands" as part of the indicator name. Some other indicators are also subsets (e.g., the persistence of pollinating vertebrates is a subset of the persistence of all terrestrial vertebrates). All subsets are shown as unfilled symbols in the plots that follow; to avoid 'double counting', they are omitted when calculating averages across indicators. The Supplementary Materials define and explain each indicator, its source and how it has been treated here, along with (where possible) how the natural baseline was estimated and plots of how the indicators has changed over time. In this section, italics are used to highlight indicators plotted in the figures for each Essential Biodiversity Variable class. Chapter 3 considers many of the same indicators, sometimes with very different presentation and analysis reflecting that chapter's different scope. Indicators that are designed to report on trends in nature directly responsible for particular classes of NCP are developed and presented in chapter 2.3.

2.2.5.2.1 Ecosystem structure

(N.B. Italics denote indicators plotted in **Figure 2.2.8**)

Most global indicators show a net deterioration in the structure (i.e., extent and physical condition) of natural ecosystems since 1970 of at least 1% per decade **(Figure 2.2.8A)**, and indicators have fallen to by almost half of their natural baseline levels (to a median of 53.2%: **Figure 2.2.8B**). There can be no doubt that human actions have radically changed, and are continuing to change, ecosystem structure – especially in sensitive ecosystems – across much of the world. Given that ecosystem structure sets the stage for ecological, evolutionary and social-ecological processes, these changes potentially jeopardize nature's ability to deliver many societal benefits. The indicators that can be estimated within the terrestrial hotspots of rare species have lower status and steeper declines there than across the globe, which is particularly concerning for biodiversity conservation; conversely, these indicators have better current status and slower declines in indigenous lands than globally.

Indicators of coastal and shallow marine ecosystems are already at low levels and are continuing to decline particularly rapidly (e.g., seagrass meadow area Waycott *et al.*, 2009; mangrove forest area Hamilton Stuart & Casey, 2016; live coral cover on reefs Eddy *et al.*, 2018; Ortiz *et al.*, 2018). The declines have direct societal implications. For example, coastal protection habitats (Ocean Health Index, 2018) protect against storm surges and can elevate coastlines in step with rising sea level (Spalding *et al.*, 2016),

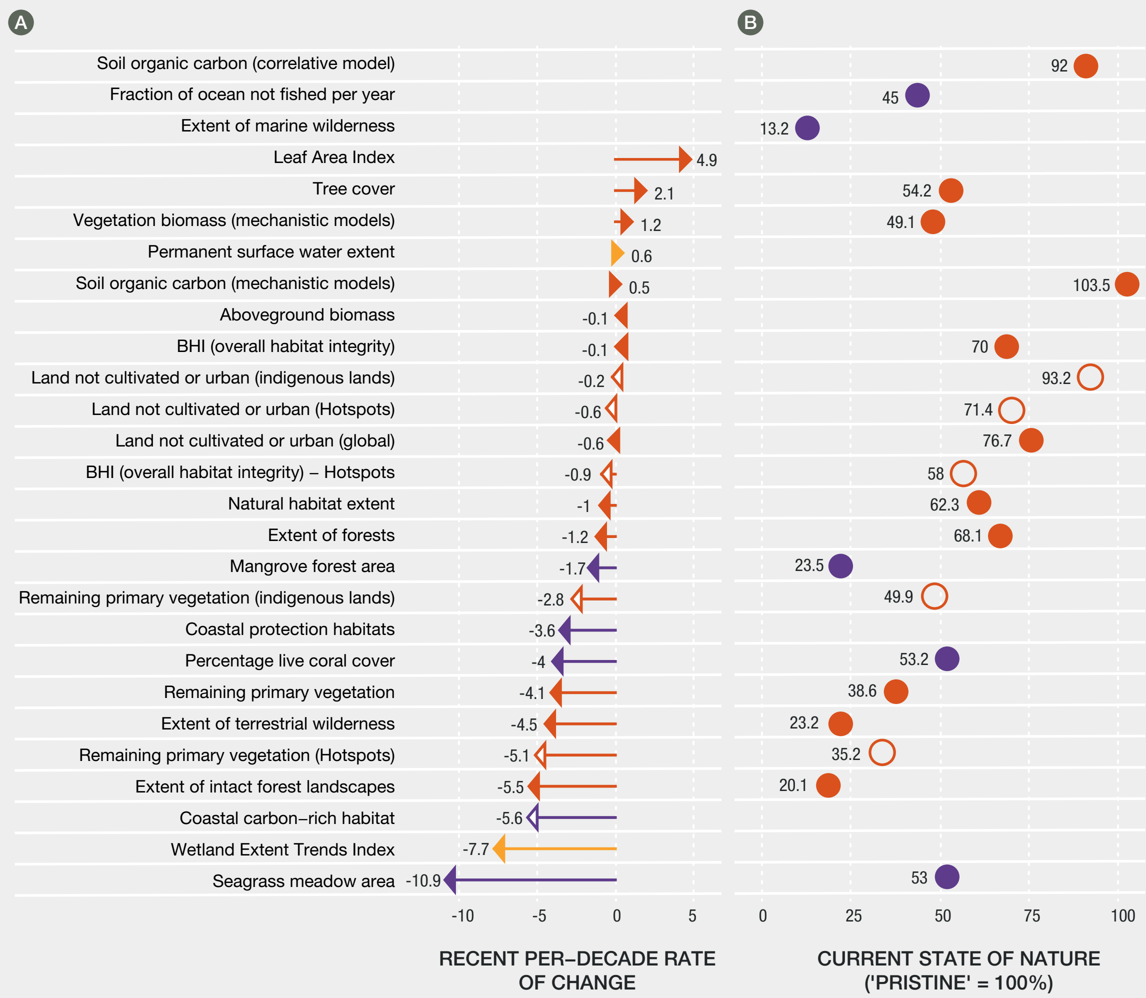


Figure 2 2 8 **Global indicators of natural ecosystem structure.**

Marine indicators are in purple, terrestrial in orange and freshwater in yellow. Solid symbols are used for overall indicator values, whereas hollow symbols show the indicator is a subset of another. A Trends, shown as the average per-decade rate of change since 1970 (or since the earliest post-1970 year for which data are available), ordered by rate of change. Most indicators show declines (left-pointing arrows; 14/17 overall indicators) and the median change overall is -1.1% per decade. B Estimated current status relative to a pristine or at largely pre-industrial baseline. On average, status is only just over half of the baseline value (median = 53.2%). Note that, even though tree cover has a positive trend in recent decades, earlier declines mean it is still well below its natural baseline. Some indicators provide only either rate or status so appear in only one panel. The Supplementary Materials provide detailed information and full references for each indicator, including subsets.

and coastal carbon-rich habitats (Ocean Health Index, 2018) can act as carbon sinks.

Other sensitive ecosystems also combine rapid decline with low levels relative to historical baselines. For example, only 13% of ocean (including almost none of most coastal ecosystems) (Jones *et al.*, 2018) and 23% of land (most of it inhospitable or remote; Watson *et al.*, 2016) are sufficiently free of obvious human impacts to still be classed as *wilderness* (and see 2.2.4 for discussion of likely human influence even there). *Intact forest landscapes* (defined as areas of forest or natural mosaics larger than 500 km^2 where satellites can detect no human pressure) continue to decline rapidly in both rich and poor countries, and especially in the Neotropics, due to industrial logging, agricultural expansion, fire and mining (a loss of 7% between 2000 and 2013; Potapov *et al.*, 2017). Estimates of the fraction of land that can still be viewed as 'natural' rather than anthropogenic range from under 25% (Ellis & Ramankutty, 2008) to over 50% (FAO, 2014a; Sayre *et al.*, 2017), depending on how 'natural' is defined. Just 39% of land area is still classed as *primary vegetation* (i.e., has never been cleared or regularly grazed; Hurtt *et al.*, 2018), putting many species of habitat specialists at potential risk (Brook *et al.*, 2003; Matthews *et al.*, 2014). The *Biodiversity Habitat Index* (Hoskins *et al.*, 2018), which recognizes that modified habitat still supports some biodiversity, estimates the current global integrity of terrestrial habitat for native biodiversity to be 70% of its original natural level. The *Wetland Extent Trend Index* is declining rapidly (Dixon *et al.*, 2016) and as much as 87% of the natural wetland in 1700 was lost by 2000 (Davidson, 2014) (see also 2.2.7.9). The slight net increase in the *extent of permanent surface water* masks extensive turnover: 13% of the area of permanent water in the 1980s had been lost by 2015, outweighed by a 16% expansion largely from new reservoirs (Pekel *et al.*, 2016).

Although *land neither cultivated nor urban* (based on satellite data and including grazing land; ESA, 2017) has decreased only slowly since 1992, much more rapid declines are seen in some units of analysis (temperate grasslands, -2.5%; tropical and subtropical forests, -1.3%; see Supplementary Materials 2.2.2.9). Some regions have also seen particularly rapid land cover change: between 2001–2012, the Arctic saw a 52% increase in the extent of forest, 19% increase in wetland and a 91% decrease in barren ground (Shuchman *et al.*, 2015).

Another indicator with marked regional variation is *aboveground biomass* **(Figure 2.2.9)**: globally, it fell by only ~ 0.2% (< 1 PgC) between 1990 and 2012 (with a dip in the mid-2000s), but tropical forests saw a fall of ~ 5 PgC (especially in Amazonia and Southeast Asia) while boreal and temperate mixed forests saw a rise of ~ 2.3 PgC (Liu *et al.*, 2015). Land-use change and intensification have reduced *vegetation biomass* – of which trees are the main component – to below 50% of the level expected if there were no human land use, mostly before 1800 (Erb *et al.*, 2018), with model-ensemble estimates (Le Quéré *et al.*, 2018) showing an upward trend since 1970 driven by CO_2 fertilization, climate change and regrowth after previous land-use change.

The indicators relating to forest structure suggest that deforestation has gone beyond the precautionary 'safe limit' for land-system change proposed in the Planetary Boundaries framework (Steffen *et al.*, 2015b). That framework argues that reduction of forests below 75% of their natural extent risks dangerous reduction in biotic regulation of global climate, though there is uncertainty over exactly where the danger point lies (Steffen *et al.*, 2015b). The global area of *tree cover* (assessed from remote-sensing data; Song *et al.*, 2018) is estimated to be only 54.2% of the area at the dawn of human civilization, while current *extent of forests* (defined as having tree cover >10%, aggregated from national statistics; FAO, 2016a) is 68.1% of their pre-industrial extent. These values are 1250 million ha and 460 million ha, respectively, below the proposed safe limit; as a comparison, Brazil's area is 852 million ha.

Deforestation has slowed since its peak in the 1990s. The *extent of forests* fell markedly more slowly in 2005–2015 than in 1990–2005 (FAO, 2016a), and global *tree cover* has actually risen, by 2.6% per decade from 1982–2016 (Song

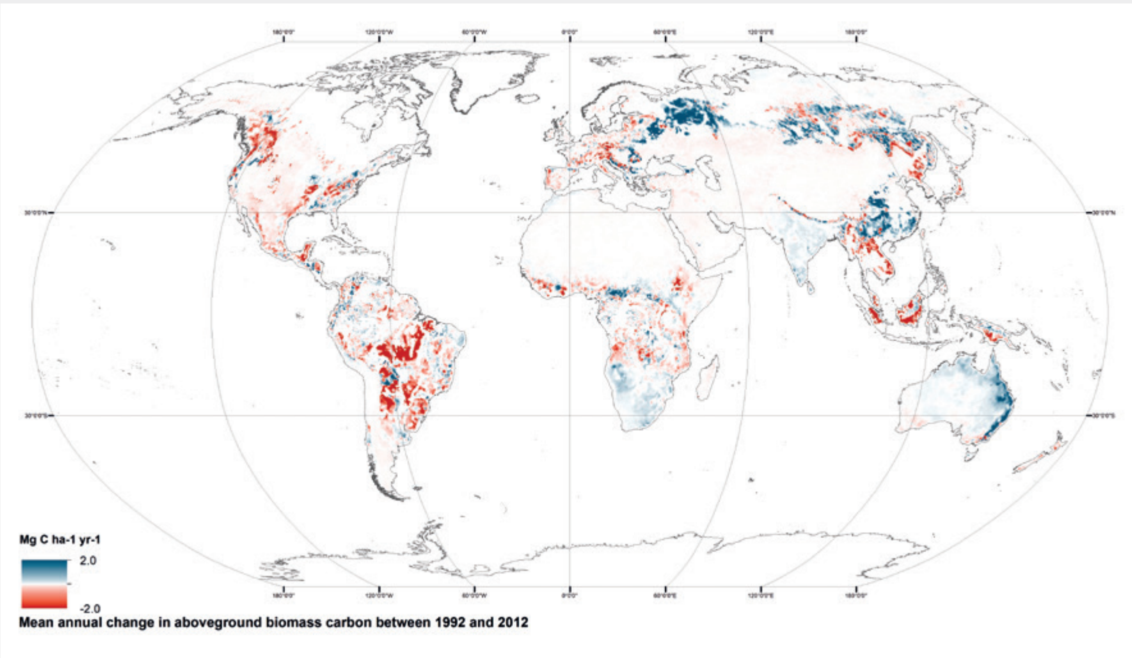


Figure 2 2 9 **Mean annual change in aboveground biomass from 1993 to 2012; data from Liu *et al.* (2015).**

et al., 2018). However, both indicators are still falling in the tropics while rising in temperate and boreal regions (FAO, 2016c; Song *et al.*, 2018); and approximately 15.3 billion trees are still being lost each year, through deforestation, forest management, disturbance and land-use change (Crowther *et al.*, 2015).

The rapid increase in *leaf area index* that is apparent **(Figure 2.2.8)** (the area of leaves per unit area of land) is largely driven by changes in north temperate latitudes where climate change has increased annual plant growth (Zhu *et al.*, 2013). Mechanistic models (Le Quéré *et al.*, 2018) infer that global *soil organic carbon* (see **Figure 2.2.8B**) now stands at 104% of the level in the 1860s; but an alternative correlative approach estimates that land use has reduced levels to 92% of their natural baseline (Van der Esch *et al.*, 2017). These diverging estimates could be partly reconciled if much of the loss caused by land-use change was before 1860; but more observation and modelling are needed.

For the indicators where we were able to make the comparison, ecosystem structure is on average less intact and declining more rapidly in the terrestrial hotspots of species rarity (as demarcated in Section 2.2.3.4.2) than across the world as a whole. Only 35.2% of their land area is still classed as *primary vegetation* and per-decade loss has averaged -5.1% of the 1970 level (the global figures are 39% and -4.1%, respectively). The corresponding values for *land neither cultivated nor urban* (ESA, 2017) in hotspots (71.7% and –0.6% per decade) are also worse than across the world as a whole (76.7% and -0.2%, respectively: **Figure 2.2.10**). The habitat integrity (*Biodiversity Habitat Index* (Hoskins *et al.*, 2018)) of these rarity hotspots is only 58%, much less than the overall global estimate of 70%.

By contrast, ecosystem structure is on average more intact and declining more slowly in indigenous lands than across the world as a whole. Nearly 50% of mapped indigenous land (Garnett *et al.*, 2018) is still *primary vegetation* (Hurtt *et al.*, 2018); and the rate of decline is only –2.8% per decade. Likewise, 93.2% of indigenous land (Garnett *et al.*, 2018) is *neither cultivated nor urban* (ESA, 2017), and this fraction is declining only a third as rapidly in indigenous lands as it is globally (-0.2% versus -0.6% per decade).

Knowledge gaps: There are few indicators for the structure of freshwater or marine ecosystems, especially in the

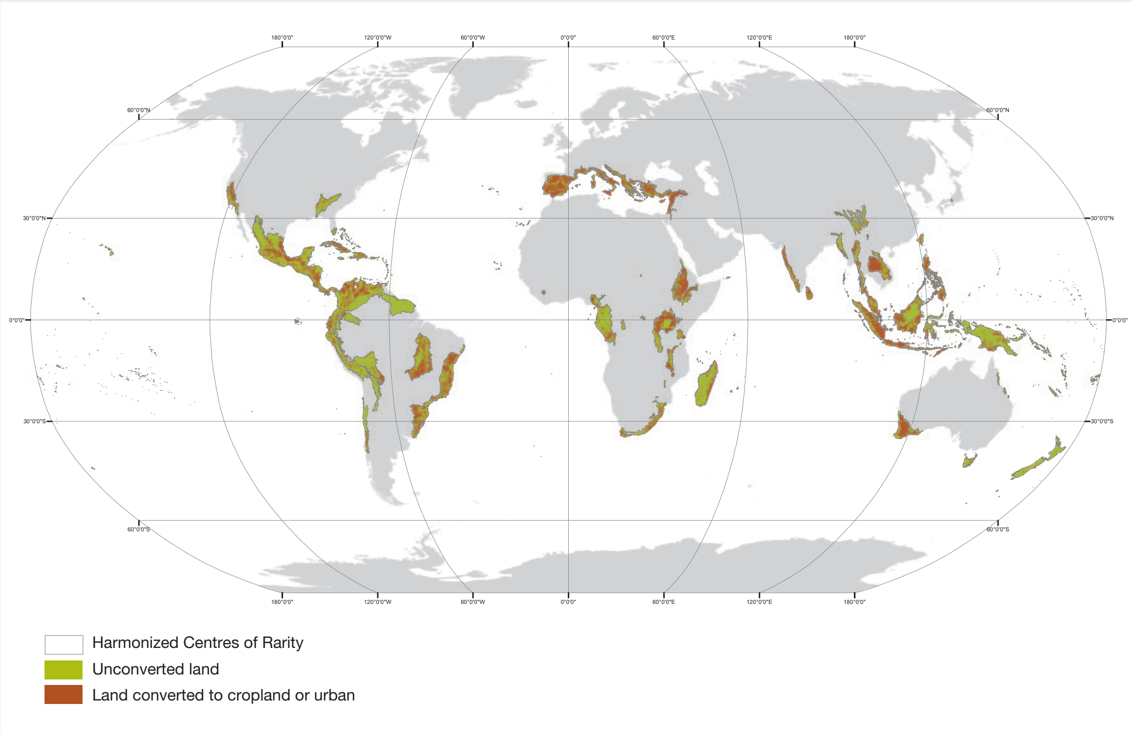


Figure 2 2 10 **Many terrestrial hotspots of endemic species (harmonized across multiple taxonomic groups as in Figure 2.2.3, Section 2.2.3.4.2) have experienced widespread conversion of natural habitat to cropland and urban areas, according to satellite-derived land-cover data (ESA, 2017).**

deep sea. Ecosystem condition is less well represented than ecosystem extent (because it is harder to measure consistently across space and over time), meaning that important degradation of ecosystem structure may be missed. For example, an estimated 35.9 Pg of soil was lost to erosion in 2012, 2.5% more than in 2001 (Borrelli *et al.*, 2017), with soil eroding from conventional agricultural landscapes far more rapidly than it is formed (FAO & ITPS, 2015). Land degradation – of which soil erosion is but one facet – is a global problem, affecting all land systems in all countries, but there is no quantitative consensus on its extent or trend (IPBES, 2018): e.g., estimates of the still undegraded fraction of the land surface range from 75.8% to 96.8% (Gibbs & Salmon, 2015). Estimates of the current global extent of grazing land also vary widely (Phelps & Kaplan, 2017; Prestele *et al.*, 2016).

2.2.5.2.2 Ecosystem function

(N.B. Italics denote indicators plotted in **Figure 2.2.11**)

Evidence suggests that rates of some fundamental ecosystem processes have accelerated greatly **(Figure 2.2.11)**. For example, the terrestrial *biomass turnover rate* – how quickly biomass is broken down and replaced – has nearly doubled on average; has increased more than tenfold in croplands and artificial grasslands; and has increase at least threefold in East and South Asia and Western, Eastern and Southern Europe (Erb *et al.*, 2016).

Two differently-estimated indicators of *terrestrial Net Primary Production (NPP)* – which forms the base of most ecological food webs and material NCP – suggest slightly different trends. An ensemble of process-based models (Le Quéré *et al.*, 2018) suggests terrestrial NPP has risen by 2.6% per decade since 1970 – though the trend is flat over the past decade – and is now nearly 30% higher than in the 1860s (the earliest decade modelled). These models all assume that rising atmospheric CO_2 boosts photosynthesis, but the magnitude of this CO_2 fertilization effect is highly uncertain (Wenzel *et al.*, 2016). In contrast, estimates derived instead from satellite data (Zhao & Running, 2010) suggest a less rapid (and not statistically significant) increase, over the much shorter time period for which the data are available (Wang *et al.*, 2012). The approaches agree, however, that the overall change masks wide spatial heterogeneity in the trend (**Figure 2.2.12**; Zhao & Running, 2010). *Marine NPP* (Behrenfeld & Falkowski, 1997) rose by 4.7% from 1998–2007.

Carbon sequestration from the atmosphere helps to slow climate change, making it another important ecosystem function to measure. The ensemble of process-based models suggest *terrestrial carbon sequestration* has recently been rising by 25% per decade and *oceanic carbon sequestration* by 29% per decade (Le Quéré *et al.*, 2018), despite a slight reduction in the *efficiency of the biological pump* (Cael *et al.*, 2017).

The annual amount of *NPP remaining in terrestrial ecosystems* after human appropriation (Krausmann *et al.*, 2013) is now around 86% its inferred natural baseline level (though only 64% in Asia). Its slow net change through history probably reflects a near-balance between

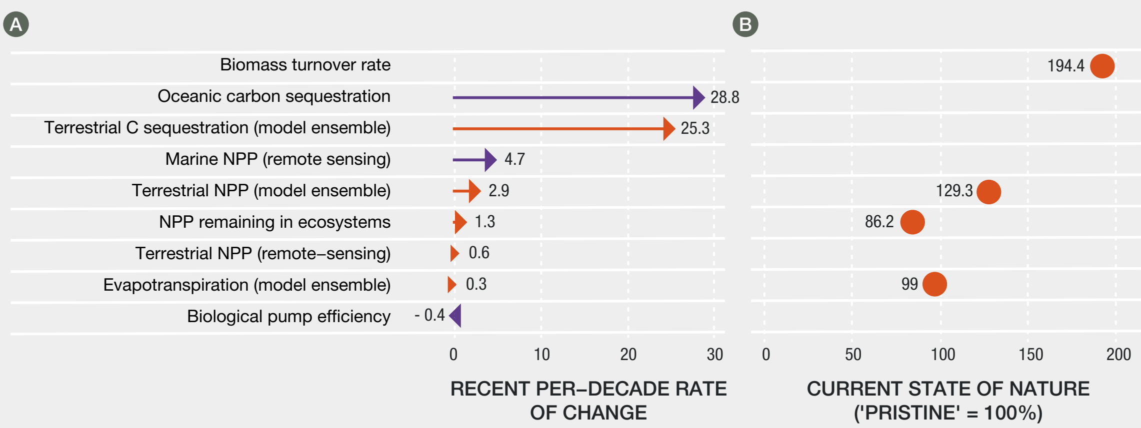
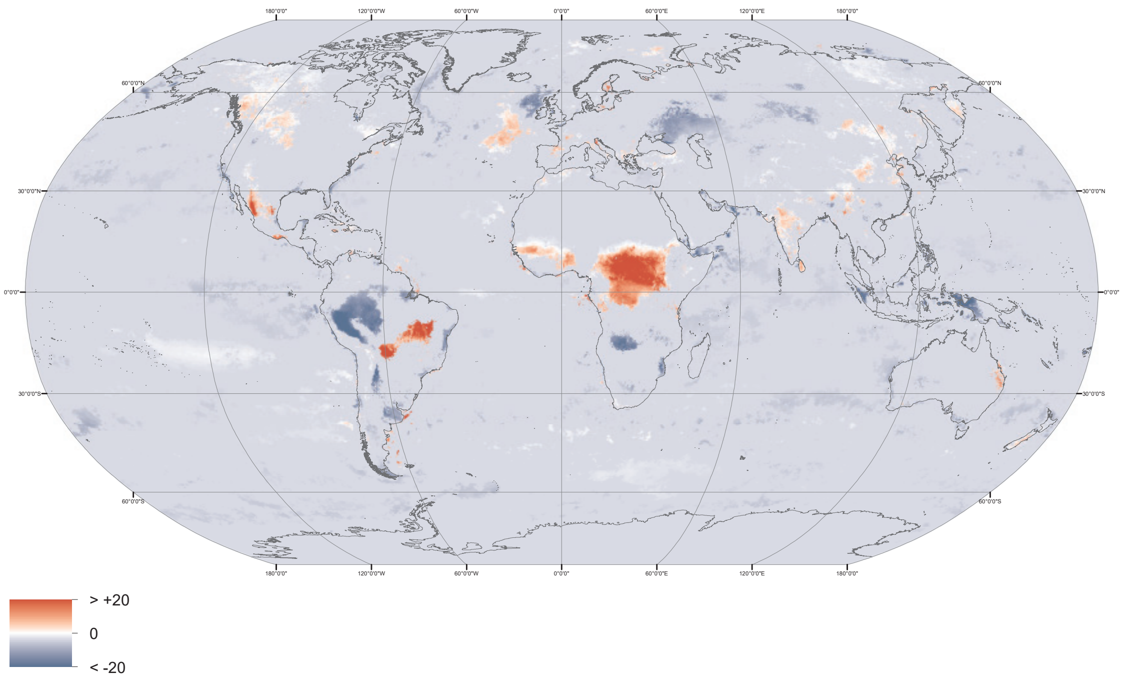


Figure 2 2 11 **Global indicators of rates of ecosystem function.**

Marine indicators are in purple, terrestrial in orange. A Trends, shown as the average per-decade rate of change since 1970 (or since the earliest post-1970 year for which data are available), ordered by rate of change; seven of the 8 global indicators suggest rates have been increasing (right-pointing arrows). B Estimated current status relative to a pristine or at least largely pre-industrial baseline. Some indicators provide only either rate or status so appear in only one panel. See Supplementary Material S 2.2.3 for detailed information on each indicator and its trend.



Global Net Primary ProductivityTrend 2003 - 2015 (gC/m2/year2)

Figure 2 2 12 **Spatial variation in the trend in terrestrial and marine NPP from 2003-2015, estimated from remote sensing data (terrestrial: Zhao & Running, 2010; marine: Behrenfeld & Falkowski, 1997).**

Note that the spatial pattern has itself changed over time, so may be different in other time windows.

increasing human appropriation of NPP and increasing NPP caused by land management and (increasingly in recent decades) CO_2 fertilization (Krausmann *et al.*, 2013). However, the biotic consequences could be much greater than such a small net change might suggest: agriculture has increasingly channeled terrestrial NPP through a relatively small set of species, reducing the diversity of forms in which that NPP is available to the species in ecosystems.

Knowledge gaps: Ecological communities carry out many more ecosystem functions vital for ecosystem health and the delivery of NCP, such as pollination, decomposition, fruit and seed dispersal, pest control and fertilization of the soil (Díaz *et al.*, 2018; see chapter 2.3); however, available indicators mostly report on either the status of the species responsible or the NCP, rather than on the ecosystem functions and processes linking the two. This partly reflects the difficulties of scaling from local sites, where ecosystem function can be measured, to the globe. More global indicators are needed of rates of ecosystem processes that directly underpin particular NCP or that indirectly underpin ecosystem health.

2.2.5.2.3 Community composition

(N.B. Italics denote indicators plotted in **Figure 2.2.13**)

Local communities are not on average showing rapid changes in species richness, but their biotic integrity is being eroded rapidly by changes in which species are present and abundant (**Figure 2.2.13**, blue background). Local assemblages are also becoming more similar to each other, a pattern known as biotic homogenization. At regional scales, the numbers of species – especially non-native species – have tended to increase over recent decades (**Figure 2.2.13**, orange background).

a. Composition of local communities

The average balance between gains and losses of species in local assemblages worldwide remains unclear (Cardinale *et al.*, 2018), largely because rates of gain (of alien, disturbance-tolerant or other human-adapted species, or of climate migrants) and of loss (though local extinction) are very context-dependent (e.g., Thomas, 2013). The *BioTime species-richness* indicator, estimated as the average trend from a compilation of time-series data from local terrestrial, freshwater and marine assemblages around the world (Dornelas *et al.*, 2014), shows a slight but not statistically significant increase on average with very wide variation from site to site (Dornelas *et al.*, 2014). A compilation of coastal marine assemblages tended to gain species over time, but sites facing local human impacts tended to lose species, especially rare species (Elahi *et al.*, 2015); and a set of local plant communities showed an average decrease in species richness in the tropics but an increase in north temperate regions (Vellend *et al.*, 2013) – assemblages facing disturbance tend to lose species whereas those recovering after disturbance tend to show gains (Gonzalez *et al.*, 2016). Geographic biases in such collations mean they may not accurately reflect the widespread increase in drivers over recent decades (Elahi *et al.*, 2015; Gonzalez *et al.*, 2016). The *PREDICTS species-richness* indicator (Hill *et al.*, 2018), which tries to overcome such geographic biases using a statistical model, shows a slight decrease over time; but the statistical model does not incorporate effects of alien species (Newbold *et al.*, 2015).

Two indicators – *Biodiversity Intactness Index* (BII; De Palma *et al.*, 2018; Hill *et al.*, 2018) and *Mean Species Abundance* (Schipper *et al.*, 2016) – agree that biotic integrity has declined on average to well below its proposed safe limit in the Planetary Boundaries scheme (Steffen *et al.*, 2015b). That framework suggests that large regions whose biotic integrity – i.e., the fraction of originally-present biodiversity that remains – falls below 90% risk large-scale failure of ecosystem resilience that would cause critical reductions in the flows of nature's contributions to people (Steffen *et al.*, 2015b) though there is a great deal of uncertainty about precisely where any boundary should be placed (Mace *et al.*, 2014; Steffen *et al.*, 2015b). A global model (Hill *et al.*, 2018) estimates the *Biodiversity Intactness Index* (BII) to average only 79% across terrestrial ecosystems **(Figure 2.2.14)**, with most biomes below 90%; a model focused on tropical and subtropical forest biomes (De Palma *et al.*, 2018) estimates an even lower BII and more negative trend, as does the global model of *Mean Species Abundance* (Schipper *et al.*, 2016). For both BII indicators and Mean Species Abundance, hotspots of rare and endemic species

Figure 2 2 13 **Global indicators of community composition at the local scale (green background) and the regional scale (orange background).**

Orange symbols are terrestrial indicators, grey symbols are indicators that combine terrestrial, freshwater and marine data. Solid symbols represent overall values for indicators, whereas semi-transparent points represent values for subsets (e.g., for a particular biome or functional group) of the overall indicator. A Trends, shown as the average per-decade rate of change since 1970 (or since the earliest post-1970 year for which data are available), ordered by rate of change. B Estimated current status relative to a pristine or at largely pre-industrial baseline. Some indicators provide only either rate or status so appear in only one panel. Supplementary Materials S 2.2.4 and S 2.2.5 have detailed information and full references for each indicator, including subsets.

have a lower current status and a more negative trend than the global average, whereas indigenous lands have a better current status (though still below the proposed Planetary Boundary) and usually a slower rate of decline **(Figure 2.2.13)**.

b. Compositional dissimilarity between assemblages

Local assemblages are becoming more similar to each other on average, a phenomenon termed biotic homogenization (McKinney & Lockwood, 1999) or the 'anthropogenic blender' (Olden, 2006). When human actions add species to a local assemblage, they are often likely to add the same species to many other assemblages within the region or even around the world; e.g., we plant and farm a relatively small number of species over vast areas of land. The structural, chemical and biotic sameness of these anthromes means that species adapted to them, whether alien or native, can spread widely. Shipping transports ballast water, and its complement of species, from one harbour to another. We move the same pets, pests, pathogens and ornamental species around the world. All of these additions are likely to make the assemblages more similar. At the same time, the species lost from local assemblages because of human actions often differ from place to place, in which case their loss also makes assemblages more similar. A global synthesis reported significant homogenization across nearly all taxonomic groups at nearly all scales (Baiser *et al.*, 2012); further support comes from regional syntheses (e.g., Rahel, 2000; Solar *et al.*, 2015; Winter *et al.*, 2009) and the most detailed field studies (e.g., Gossner *et al.*, 2016).

c. Composition of regional assemblages

Numbers of species in assemblages at larger spatial scales – such as countries or 0.25° grid cells – have tended to increase over recent decades (**Figure 2.2.13**, orange background), partly driven by rapid increases in numbers of non-native species (McGill *et al.*, 2015; Thomas, 2013). A global analysis of establishment of species in new countries from a wide range of taxonomic groups found the *cumulative number of alien species* is rising by 13% per decade, with 37% of all reported establishment events being since 1970 (Seebens *et al.*, 2017). Across 21 countries with particularly good recording of *introduced invasive alien species* (i.e., aliens that cause ecological or economic problems), numbers per country have increased by an average of 70% since 1970 (Pagad *et al.*, 2015). Among the most widespread invaders are the black rat (*Rattus rattus*, 23% of the world's countries), water hyacinth (*Eichhornia crassipes*, 30%), Eastern mosquitofish (*Gambusia holbrooki*, 30%), purple nutsedge (*Cyperus rotundus*, 37%), and cottony cushion scale insects (*Icerya purchasi*, 42%) (Turbelin *et al.*, 2017). Many crop pests and pathogens, especially fungal pathogens, have become widespread, tracking the regional expansion of their host crops (Bebber *et al.*, 2014).

Over 13,000 plant species of plant have become established in countries outside their native range (van Kleunen *et al.*, 2015). Numbers of plant species have increased by an average of 20%–25% across continental regions in Europe and the USA because establishment of aliens has exceeded losses of natives at this scale (Vellend

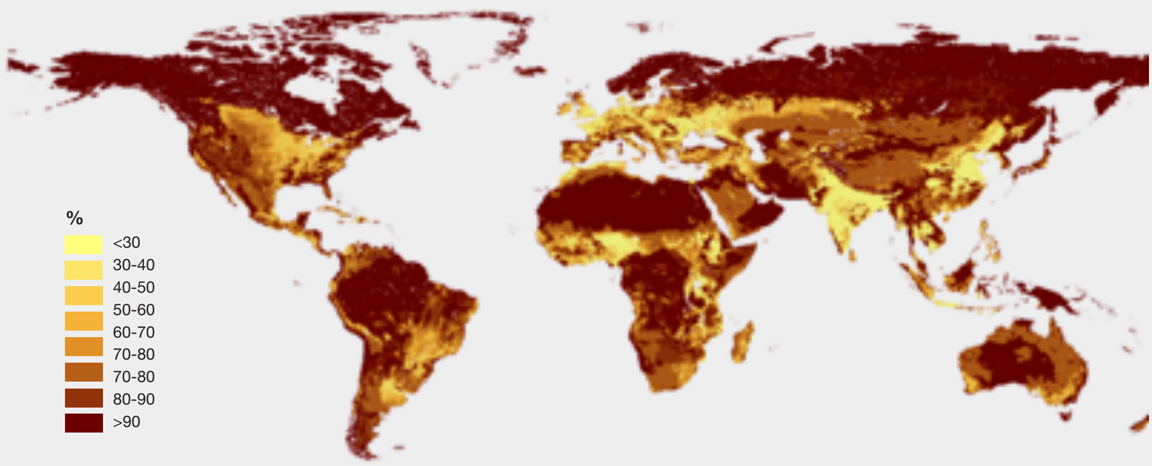


Figure 2 2 14 **Global map of estimated terrestrial Biodiversity Intactness Index in 2015 (Hill *et al.*, 2018).**

Darker colours indicate more intact ecological community composition.

et al., 2017); regional plant species richness is estimated to have increased by 5% or more across nearly half of the world's land surface and decreased similarly across only 14% (Ellis *et al.*, 2012). Alien species make up a smaller fraction of the flora in tropical countries than in temperate ones, but too little is known about national extinctions in the tropics to be sure that the net change there has been an increase (Vellend *et al.*, 2017). *Species richness per grid cell* (Kim *et al.*, 2018)*,* modelled across plants, birds, mammals, amphibians and reptiles, has fallen slightly since 1970 because of changes in land use and climate. However, this model omits species introductions (Kim *et al.*, 2018), which would make the trend more positive; and, even without introductions, the indicator is still higher than in 1900 for most groups. A conceptually similar model (Kim *et al.*, 2018; Pereira & Daily, 2006) estimates that *bird species per grid cell* has risen slightly since 1970, but that *forest-specialist bird species per grid cell* has fallen, and more steeply. A mechanistic general ecosystem model (Harfoot *et al.*, 2014) suggests that average *functional intactness* (i.e., the extent to which a region's species still occupy the functional trait space of its native species) is falling because of harvesting of primary productivity and climate change (Kim *et al.*, 2018).

Island assemblages are likely to be an exception to the general trend towards increased species numbers. They can be devastated by invasive alien species (e.g., Bergstrom *et al.*, 2009; O'Dowd *et al.*, 2003; Reaser *et al.*, 2007), in part because native species may have evolved in the absence of strong competition, predation or pathogens (Courchamp *et al.*, 2003). Introduced mammalian predators have removed many native bird species from oceanic islands worldwide (Blackburn *et al.*, 2004), reducing diversity at the island scale. Introduced plant species, by contrast, have roughly doubled the numbers of plant species on a set of well-documented oceanic islands (Carvallo & Castro, 2017; Sax & Gaines, 2008). Even though they may increase regional diversity, though, invasive alien plants usually reduce numbers of species in local assemblages on islands (Pyšek *et al.*, 2012) and can have profound ecosystem impacts (e.g., Dulloo *et al.*, 2002; Pyšek *et al.*, 2012).

Some invasive alien species on mainlands can also drive reductions in regional-scale diversity, by causing native species to decline. *Batrachochytrium dendrobatidis*, an infectious fungal pathogen that has infected over 700 amphibian species worldwide, has caused a number of extinctions, and is recognized as a threat to nearly 400 species (Bellard *et al.*, 2016; Lips, 2016; Olson *et al.*, 2013).

Even where regional species richness has increased, the increase may be temporary because an 'extinction debt' has not yet been repaid (Jackson & Sax, 2010). Biotic responses to drivers of change are often not immediate, meaning recent intensification of any driver can produce 'dead species walking', certain to disappear from the region unless the drivers of their decline are reversed (Kuussaari *et al.*, 2009). Extinction debts are discussed in more detail in Section 2.2.5.2.4a below.

Knowledge gaps: Available indicators all relate to the taxonomic or functional composition rather than the interactions among organisms and taxa. Indicators overwhelmingly relate to terrestrial free-living animal and plant species: freshwater and marine assemblages are greatly underrepresented, and microbial and parasite assemblages entirely so. As yet there are no global indicators of biotic homogenization.

2.2.5.2.4 Species populations

(N.B. Italics denote indicators plotted in **Figure 2.2.16**)

a. Extinctions, extinction risk and extinction debt

The most direct evidence on global extinctions and extinction risk comes from the detailed assessments of species' conservation status undertaken by the IUCN (International Union for the Conservation of Nature). IUCN has assessed the global conservation status of 93,579 species, mostly vertebrates, of which 872 (0.9%) have gone extinct since 1500 (IUCN, 2018). Under-recording and time lags in recognizing extinction events make this a certain underestimate of the true number (Alroy, 2015; Dunn, 2005; Pimm *et al.*, 2006; Scheffers *et al.*, 2012; Stork, 2010), especially in less well studied groups (e.g., only 62 species of insect are listed as extinct; but fewer than 1% of insects have been assessed; IUCN, 2018) and habitats (e.g., only 20 marine extinctions have been recorded; Webb & Mindel, 2015). In the best-recorded groups, mammals and birds, around 1.4% of species are known to have gone globally extinct since 1500, most of them since 1875 (IUCN, 2018).

The global rate of species extinction is already at least tens to hundreds of times higher than the average rate over the past 10 million years, and is accelerating (Barnosky *et al.*, 2011; Ceballos *et al.*, 2015; Pimm *et al.*, 2014); the difficulties of estimating and comparing current and past extinction rates (Barnosky *et al.*, 2011; Ceballos *et al.*, 2015; Pimm *et al.*, 2014) preclude greater precision. The extinction rate therefore already exceeds its proposed safe limit (set at ten times the average rate (Steffen *et al.*, 2015b)) in the Planetary Boundaries framework, though the suggestion that elevated rates may eventually trigger sharp and irreversible changes in the Earth system (Steffen *et al.*, 2015b) has been criticized (Brook *et al.*, 2013; Mace *et al.*, 2014). Extinction rates would be still higher but for successful conservation (Butchart *et al.*, 2006, chapter 3).

Extrapolating from detailed assessments of species across a growing and diverse set of well-studied taxonomic groups, it is probable that at least a million animal and plant species – more than one in eight – already face global extinction. The proportion of species currently threatened with global extinction (i.e., listed in the IUCN Red List as Vulnerable, Endangered or Critically Endangered) averages around 25% across a wide range of animal and plant taxonomic groups (range = 7.4%–63.2%, median = 22.1%; **Table 2.2.1**). The current prevalence of extinction risk appears to be similar between terrestrial and marine realms, from the few marine groups in **Table 2.2.1** and from models of how threat prevalence scales with the comprehensiveness of Red List assessments (Webb & Mindel, 2015). No global estimate of extinction risk prevalence is yet available for any of the hyperdiverse insect orders. However, a cautious estimate of 10% is reasonable, based on the Red Lists for Europe (the region with the best data), which report that 9.2% of bee species (Nieto *et al.*, 2014), 8.6% of butterflies (Van Swaay *et al.*, 2010) and 17.9% of saproxylic beetles (Cálix *et al.*, 2018) are threatened with regional extinction. For context, in vertebrates, Europe's levels of regional extinction risk are lower than the overall levels of global extinction risk (EU, 2018). If insects make up three quarters of animal and plant species (Chapman, 2009) and only 10% of them are threatened as opposed to 25% of species in other groups, then overall nearly 14% of animal and plant species are threatened with extinction, i.e., more than a million using the estimated total number of 8.1 million (Mora *et al.*, 2011).

Table 2 2 1 **Proportions of evaluated species.**

The first figure given assumes that Data Deficient species are equally likely as other species to be threatened. The range reported shows the proportion if Data Deficient species are assumed to be not threatened and threatened, respectively. Basis of estimate: all species = comprehensive assessment of whole group; sample = representative sample assessed; some families = all species within some families assessed, but families may not be representative.

Group	Threatened species (%)	Possible range (%)	Basis of estimate	Reference
Vertebrates				
Amphibians	41.49%	32-55%	all species	(IUCN, 2018)
Birds	13.47%	13-14%	all species	(IUCN, 2018)
Bony fishes	7.41%	7-18%	some families	(IUCN, 2018)
Mammals	25.17%	22-36%	some families	(IUCN, 2018)
Marine mammals	38.70%	30-52%	marine species	
Reptiles	18.99%	15-36%	sample	(Böhm *et al.*, 2013)
Sharks & rays	31.18%	18-60%	all species	(IUCN, 2018)
Invertebrates				
Crustaceans	27.49%	17-56%	some families	(IUCN, 2018)
Gastropods	7.52%	6-20%	some families	(IUCN, 2018)
Odonata	15.38%	10-45%	sample	(Clausnitzer *et al.*, 2009)
Reef-forming corals	32.91%	27-44%	all species	(IUCN, 2018)
Plants				
Cycads	63.16%	63-64%	all species	(IUCN, 2018)
Dicots	36.14%	32-44%	some families	(IUCN, 2018)
Legumes	11.30%	11-18%	sample	(Brummitt *et al.*, 2015)
Gymnosperms	40.55%	40-42%	sample	(Brummitt *et al.*, 2015)
Monocots	17.51%	15-27%	sample	(Brummitt *et al.*, 2015)
Pteridophytes	16.01%	15.9-16.4%	sample	(Brummitt *et al.*, 2015)

Numbers of threatened vertebrate species show wide geographic variation both on land and at sea **(Figure 2.2.15)**, reflecting where large numbers of narrowly-distributed species (see Section 2.2.3.4.2) face often intense, often multiple anthropogenic drivers (Hoffmann *et al.*, 2010).

The *Red List Index* (RLI) (Butchart *et al.*, 2007, 2010) tracks overall trends in survival probability (the inverse of extinction risk) of species in taxonomic groups whose IUCN Red List status has been assessed multiple times. Overall, the RLI is now only 75% of the value it would have without human impacts **(Figure 2.2.16)**, though this varies among taxonomic groups (e.g., birds have an RLI around 90% but for cycads RLI is below 60%: chapter 3). Regions showing the greatest deterioration in RLI include much of Southeast Asia and Central America (Hoffmann *et al.*, 2010). RLI values calculated for sets of species that directly deliver some NCP – *internationally-traded species*, *pollinating vertebrate species*, *species used in food and medicine*, and *wild relatives* of farmed and domesticated mammals and birds – are higher than the overall value and are declining more slowly, but they are all declining. Species' progress towards extinction appears to be increasingly rapid: half of the decline in the overall Red List Index has taken place in the last 40 years.

Few insects have global IUCN assessments, but regional and national assessments of insect pollinators often indicate high levels of threat, often more than 40% of species threatened at a national scale, particularly for bees and butterflies (IPBES, 2016). Recent European scale assessments indicate that 9.2% of bees (Nieto *et al.*, 2014) and 8.6% of butterflies (Van Swaay *et al.*, 2010) are threatened. Bee species that pollinate crops are generally common with a low prevalence of extinction risk (IPBES, 2016).

Whereas IUCN's detailed Red List assessments of species form the basis for 'bottom-up' estimates of numbers of threatened species, an alternative 'top-down' approach can be used to estimate the 'extinction debt' – i.e., how many species are expected to eventually go extinct because of habitat deterioration that has already taken place (Kuussaari *et al.*, 2009). The earliest estimates of extinction debt (Diamond, 1972) were based directly on one of the strongest patterns in biodiversity, the species-area relationship: the number of species in a region increases

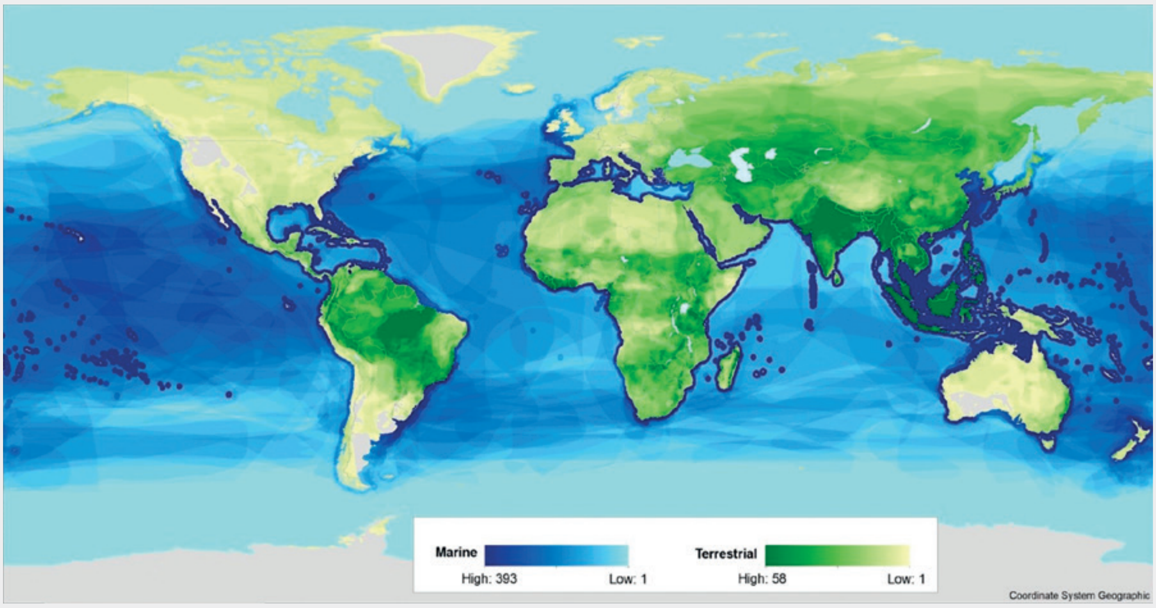


Figure 2 2 15 **Numbers of threatened (i.e., vulnerable, endangered or critically endangered) species per 10km grid cell, pooled from comprehensive geographic distribution and extinction-risk assessments of multiple taxonomic groups.**

Green = terrestrial (amphibians, birds, chameleons, crocodiles/alligators and mammals); blue = marine (angelfish, birds, blennies, bonefish/tarpons, butterflyfish, marine turtles, sharks/rays, Conus cone shells, corals, damselfish, groupers, hagfish, lobsters, mammals, mangroves/seabreams/porgies, pufferfish, sea cucumbers, seagrasses, sea snakes, sturgeonfish/tangs/unicornfish, tunas/billfishes and wrasse; grey = no data. Darker colours indicate higher numbers of threatened species. Note that only a small minority of taxonomic groups have so far been assessed, with a bias towards vertebrates especially on land. Methods as in Hoffmann *et al.* (2010). Figure produced by UNEP-WCMC.

predictably with its area (often as a power law), because larger regions both have greater habitat diversity and can support larger numbers of viable populations (Lewis, 2006; Rosenzweig, 1995). Habitat loss effectively makes the region smaller. Though this loss of area may not wipe any species out immediately, it means that the region now has more species than expected: this excess of species is the extinction debt, and all the region's species will have elevated probabilities of extinction until the diversity falls back to the level expected from the species-area relationship. Such approaches do not identify precisely which species in the region will go extinct; they may not meet IUCN's criteria for being listed as threatened, for example. Nor do these approaches specify how long the extinctions will take: although the first extinctions may arrive quickly, the last ones may take centuries, especially in large regions and/or when species have long generation times (Halley *et al.*, 2016; Kuussaari *et al.*, 2009; Vellend *et al.*, 2006). The estimates of extinction debt used here come from models with more sophisticated species-area relationships that consider species' habitat preferences and geographic distributions, and habitat condition as well as extent (Hoskins *et al.*, 2018; Kim *et al.*, 2018; Pereira & Daily, 2006), meaning many of the criticisms of earlier approaches (He & Hubbell, 2011; Lewis, 2006; Pereira *et al.*, 2012) no longer apply. Furthermore, they use entirely different data and methods from the Red List assessments, so provide a completely independent line of evidence.

The most comprehensive global estimate available (Hoskins *et al.*, 2018) suggests that the terrestrial extinction debt currently stands at hundreds of thousands of animal and plant species. The loss of terrestrial habitat integrity estimated by the *Biodiversity Habitat Index* (Hoskins *et al.*, 2018), when coupled with the species-area relationship, suggests that only 92.1% of terrestrial vertebrate species, 91.6% of terrestrial invertebrates and 90.7% of terrestrial plants have sufficient habitat to persist. The numbers of plant and especially animal species remain very uncertain (Caley *et al.*, 2014; Scheffers *et al.*, 2012), but a recent non-extreme estimate of 8.1 million of which 2.2 million are marine (Mora *et al.*, 2011), these proportions suggest that around half a million terrestrial animal and plant species are 'dead species walking', committed to extinction unless their habitats improve in time to prevent it. This total includes over 3000 vertebrates and over 40,000 plants. Even this estimate may be conservative, as undocumented diversity of arthropods, parasites and soil microfauna could mean there are 2–25 times more animal species than assumed here (Larsen *et al.*, 2017), and fungi are not included (Scheffers *et al.*, 2012). Using a related approach, the countryside species-area relationship (cSAR), to estimate the *global bird richness* that can persist suggests that 97.6% of the world's bird species, but only 94.9% of forest-specialist birds, will avoid extinction resulting from past habitat loss.

These two very different lines of evidence both point to a further sharp acceleration in the global rate of species extinction, already at least tens to hundreds of times higher than the average rate over the past 10 million years and is accelerating. The numbers of threatened species that will go extinct if the drivers that threaten them continue, and the numbers of 'dead species walking' that will die out even without any further habitat deterioration or loss, dwarf the numbers of species already driven extinct by human actions (Johnson *et al.*, 2017; Wearn *et al.*, 2012). Rapid large-scale restoration of habitats can pardon the 'dead species walking', provided it takes place in time (Kuussaari *et al.*, 2009); and even much less widespread restoration can greatly delay extinctions if targeted optimally (e.g., Newmark *et al.*, 2017).

b. Geographic distribution and population size

Nearly all global indicators of geographic distribution (**Figure 2.2.16**, blue background) and population size (**Figure 2.2.16**, cream background) show rapid decline, reflecting widespread reductions in animal populations on land (Ceballos *et al.*, 2017; Dirzo *et al.*, 2014) and sea (McCauley *et al.*, 2015), though most global indicators focus on vertebrates. Several indicators are calculated in a way that makes them particularly sensitive to trends in rare species (Buckland *et al.*, 2011), and these all show rapid declines: *The Living Planet Index* (LPI) for vertebrate populations (McRae *et al.*, 2017); the *Wild Bird Index* for habitat-specialist birds; and the *extent of suitable habitat* for terrestrial mammals (Kim *et al.*, 2018; Visconti *et al.*, 2016). The *Species Habitat Index*, which changes in direct proportion to average species range size (Map of life, 2018), has shown more modest recent declines in terrestrial vertebrates. *Mammalian range size* has been reduced to an average of 83% of species' inferred original ranges, but *megafaunal range size* – species larger than 44.5kg – is now only 28% of the natural baseline (Faurby & Svenning, 2015), with large mammal ranges having declined particularly rapidly in south and southeast Asia (Ceballos *et al.*, 2017). *Predatory fish biomass* (which includes the main target species for fisheries (Christensen *et al.*, 2014)) has been falling by -14% per decade, and the proportion of *fish stocks within biologically sustainable levels* by 6% per decade (to less than 70%) (FAO, 2016d). The *biomass of prey fish* **(Figure 2.2.16)** has been rising by 10% per decade, the only indicator to show an increase, probably because fishing has removed predatory fish (Christensen *et al.*, 2014). Such indirect responses to anthropogenic drivers are ubiquitous and can have profound effects on many aspects of ecosystems (Dirzo *et al.*, 2014; McCauley *et al.*, 2015).

Invertebrate trends have not so far been synthesized globally, because of a dearth of tropical data. An LPI-like analysis of mainly European and North American data reported a decline of -11% per decade (Dirzo *et al.*, 2014).

The same regions have seen declines in geographic distribution and occurrence of many wild bees and butterflies (IPBES, 2016); and, of species with enough information to make an assessment, 37% of bees and 31% of butterflies are declining in Europe (IPBES, 2016; Nieto *et al.*, 2014; Van Swaay *et al.*, 2010). Available time-series data show that local declines of insects can be rapid even in the absence of large-scale land-use change (e.g., 76% decline over 27 years in biomass of flying insects in sites in 63 protected areas in Germany (Hallmann *et al.*, 2017)); it is not known how widespread such rapid declines are.

Although many species are declining, farmed species, domesticates, and species that are well adapted to anthromes have all increased in abundance. A hectare of wheat will often have more than 500,000 established plants – and wheat is planted on around 220 million ha each year (Rudel *et al.*, 2009); the number of managed western honey bee hives is increasing globally (IPBES, 2016); and livestock now accounts for over 90% of megafaunal biomass on land (Barnosky, 2008).

Knowledge gaps: There are shortages of detailed knowledge of conservation status and population trends in insect, fungal and microbial species. Tropical populations are extremely underrepresented in trend data.

Figure 2 2 16 **Global indicators of species population, reflecting persistence of species (orange background), geographic range size (green background) or population size (cream background).**

Terrestrial indicators are shown in orange, marine in purple, freshwater in yellow, and multi-realm indicators in grey. Solid symbols represent overall values for indicators, whereas semi-transparent points represent values for subsets (e.g., within hotspots of endemic species) of the overall indicator. A Trends, shown as the average per-decade rate of change since 1970 (or since the earliest post-1970 year for which data are available), ordered by rate of change. B Estimated current status relative to a pristine or at largely pre-industrial baseline. Some indicators provide only either rate or status so appear in only one panel. Supplementary Materials S 2.2.6 and S 2.2.7 have detailed information and full references for each indicator, including subsets.

2.2.5.2.5 Organismal traits

(N.B. Italics denote indicators plotted in **Figure 2.2.18**)

Human activities have driven and continue to drive widespread changes in distributions of organismal traits within populations **(Figure 2.2.17)** and in local, regional, and global assemblages (**Figure 2.2.18**, **Figure 2.2.19**). Traits not only mediate how populations and communities respond to changing environments (e.g., Diaz *et al.*, 2013; Hevia *et al.*, 2017; Jennings & Kaiser, 1998; Mouillot *et al.*, 2013; Suding *et al.*, 2008) but also strongly influence species' likelihoods of being exploited (Jerozolimski & Peres, 2003), persecuted (Inskip & Zimmermann, 2009), domesticated (Larson & Fuller, 2014), introduced (Theoharides & Dukes, 2007) or otherwise impacted by people. Rapid evolution **(Box 2.5)** contributes to the changes, alongside phenotypic plasticity (in which the environment shapes how an organism's phenotype develops) and ecological processes. The combined effects typically shift both average trait values (e.g., toward smaller body size) and the amount of trait variation (e.g., reducing the range of trait values). The changes in trait distributions matter because they can have consequences, sometimes major, for ecosystem functioning, NCP, and whether ecosystems will be resilient in the face of ongoing environmental change (Diaz *et al.*, 2013; Laliberté *et al.*, 2010; Lavorel & Garnier, 2002).

Few quantitative indicators are available that show how distributions of organismal traits have changed globally, but there is an extensive literature showing how each of the main direct drivers affects both trait distributions among and within species. This section highlights some recent examples, while **Box 2.5** focuses on within-population changes, especially heritable genetic changes – evolution.

Land-use change causes the assembly of new ecological communities, often with very different trait distributions from the community present previously. Forest removal obviously greatly changes distributions of plant traits, for instance, but also reshapes trait distributions in tropical bird assemblages: long-lived, large, non-migratory, forest-specialist frugivores and insectivores become less abundant and less widespread (Newbold *et al.*, 2013). Increasing land use led to European plant communities being dominated by shorter species with more acquisitive leaf syndromes and accelerated flowering phenology (Garnier *et al.*, 2007). Bee species' responses to changing land use in Europe depend on flight season duration, foraging range and, to a lesser extent, niche breadth, reproductive strategy and phenology (De Palma *et al.*, 2015). A global meta-analysis found that intensification of land use was associated with greater reduction of functional diversity in mammal and bird assemblages than expected from the number of species lost (Flynn *et al.*, 2009).

Direct exploitation often targets older, larger and more accessible individuals, so shifts trait distributions in the opposite direction. For example, large, diurnal, terrestrial mammals have been particularly likely to face hunting pressure (Johnson, 2002), and species of tuna and their relatives that grow and reproduce more slowly have declined more than other species in the face of fishing pressure (Juan-Jordá *et al.*, 2015). Such phenotype-dependent mortality holds both among populations within species (Darimont *et al.*, 2009), so larger-bodied species are lost from communities, larger-bodied populations are lost from species, and many populations rapidly evolve smaller body size and earlier maturation **(Box 2.5)**.

Climate change tends to shift trait distributions away from low reproductive rates, poor dispersal abilities and ecological specialism (as species with these traits are less able to persist when climate change: (Pacifici *et al.*, 2015)) and towards more flexible, environmentally responsive, phenotypes (e.g., plants: Willis *et al.*, 2008; birds: Both *et al.*, 2006; Nussey *et al.*, 2005) and earlier spring phenology in seasonal environments (e.g., earlier bud break for plants, earlier hatching and emergence for insects, and earlier breeding for birds and mammals; Parmesan & Yohe, 2003; Wolkovich *et al.*, 2012). Global changes in phenology have been dramatic: between 1981 and 2012, the phenology of vegetation (timing of leaf onset and offset) has changed by more than 2 standard deviations across 54% of the global land surface (Buitenwerf *et al.*, 2015), and growing seasons have lengthened (Linderholm, 2006), in the Arctic by more than 3 days per decade (Xu *et al.*, 2013). This information is policy relevant because it can influence decisions about assisted migration (moving species to locations where they will be better suited for the new climate; McLachlan *et al.*, 2007).

Pollution also reshapes trait distributions, in ways that differ among pollutants and species. Effects of different classes of insecticide on aquatic invertebrates, for example, are mediated by the body size, respiration type and degree of sclerotization of species, populations and individuals (Rico & Van den Brink, 2015).

Invasive alien species can increase trait and functional diversity having different trait values from natives (Hejda & de Bello, 2013; Ordonez *et al.*, 2010; Van Kleunen *et al.*, 2010), but their trait-mediated effects on native species can also change overall trait distributions. A global meta-analysis of 198 studies found that invasive plants tend to reduce diversity and abundance of herbivorous and carnivorous animals but not detritivores or omnivores (Schirmel *et al.*, 2016), thereby changing the trophic diversity of assemblages.

Indirect effects of drivers – knock-on effects – can also select against particular organismal traits and therefore affect trait distributions. Most obviously, species that depend on just one or a narrow set of other species, whether as a host, food, pollinator, or disperser, will often be vulnerable if that species declines (Dunn *et al.*, 2009).

Species' extinction risk, which integrates across all direct and indirect drivers at the global level, is strongly related to organismal traits in a wide range of taxonomic groups. The traits that are most likely to be lost from assemblages through extinction differ somewhat among groups, but commonly include habitat and dietary specialism, slow reproductive rate, and large body size (Bland, 2017; Böhm *et al.*, 2016; Cardillo *et al.*, 2005; Cooper *et al.*, 2008; Davidson *et al.*, 2009; Dulvy *et al.*, 2014; Fritz *et al.*, 2009; Lee & Jetz, 2011; Mankga & Yessoufou, 2017; Owens & Bennett, 2000).

Box 2 5 Rapid evolution.

Evolution is typically assumed to be a very slow process, with many species exhibiting remarkable stability over millions of years. This stability is mostly a function of precise adaptation to relatively stable environments; hence, when environments change rapidly, we might expect rapid evolutionary responses. Human actions mean that many species are facing radical changes in their environments, setting up the conditions for many populations to show rapid trait change. **Figure 2.2.17**, based on an extensive review of over 4000 rates of trait change from over 350 studies, reveals that each of the main direct drivers can provoke rapid trait change, as can natural disturbances.

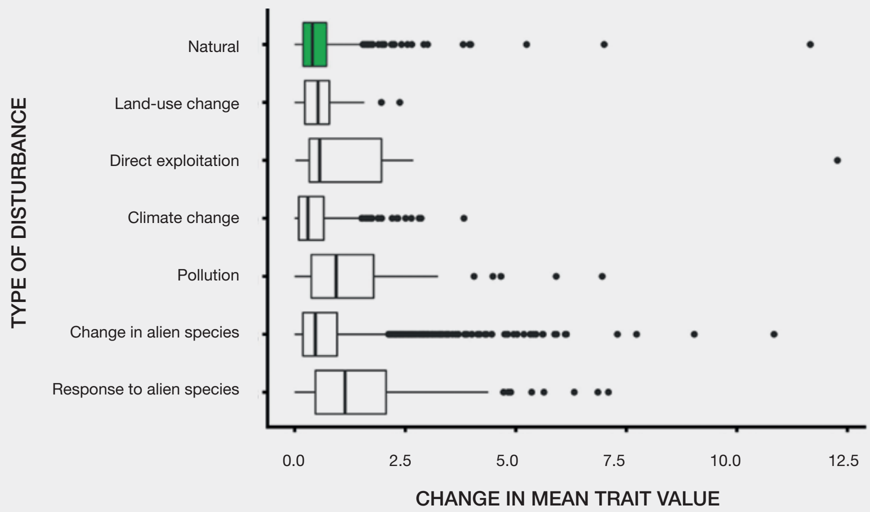


Figure 2 2 17 **Meta-analysis of published estimates of rapid changes in trait means (expressed as the population's change in the mean trait value divided by its standard deviation) within populations that faced natural disturbances or the direct anthropogenic drivers of change.**

Vertical lines indicate medians, and boxes span 25th-75th percentiles. Sample sizes: natural disturbance, 574 effects (49 studies); land-use change, 122 (19); direct exploitation, 18 (7); climate change, 327 (197); pollution 68 (12); change in alien species, 3329 (87); change in native responding to alien species, 223 (10).

Attributing rapid trait changes to evolution (genetic change), plasticity (direct environmental influences on individual development or behaviour), or a combination of both, takes additional focused investigation. Nonetheless, numerous case studies are demonstrating rapid evolution in response to each of the main direct drivers. For example:

- Land-use change caused significant genetic differentiation among plant populations in grassland sites facing different land uses and intensities, in all eight species tested (Völler *et al.*, 2017)
- Direct exploitation is likely to cause evolutionary change whenever the phenotypes it targets are under genetic control. For instance, trophy hunting of bighorn sheep drives the rapid evolution of smaller horn size (Pigeon *et al.*, 2016); while commercial fishing drives the rapid evolution of smaller size and earlier maturity (Sharpe & Hendry, 2009) – although it can be hard to prove a genetic basis underlying the change.
- Climate change is driving rapid evolution in many populations and species (Merilä & Hendry, 2014). For instance, pitcher

plant mosquitoes *(Wyeomyia smithii)* have evolved earlier pupation timing in accordance with earlier spring warming (Bradshaw & Holzapfel, 2002).

- Pollution can rapidly drive evolution of tolerance (Hamilton *et al.*, 2017), with a recent example being killifish *(Fundulus heteroclitus)* adapting to PCBs in estuaries along the eastern coast of North America (Reid *et al.*, 2016).

Cities present novel and in many ways extreme environments and are driving rapid evolution in many species (Alberti *et al.*, 2017; Johnson & Munshi-South, 2017). Two clear recent examples are the evolution of freeze-tolerance of white clover, *Trifolium repens* (Thompson *et al.*, 2016), and the evolution of significantly reduced dispersal another plant species, *Crepis sancta*, within 12 generations in response to urban habitat fragmentation (Cheptou *et al.*, 2017).

Evolutionary change in these traits likely influences the ability of organisms to persist and thrive in altered environments, a phenomenon called "evolutionary rescue" (Carlson *et al.*, 2014). Yet evolution won't always save populations or species – the outcome depends on many factors, including the demographic cost imposed by the disturbance, the strength of selection, and the genetic variation available for evolution. Hence, policy decisions that seek to maintain populations and species can manipulate these factors to maximize population persistence and productivity, and nature's contributions to people. For example, alternative harvesting regimes can drive different evolutionary changes that can have different effects on sustainability and productivity (Dunlop *et al.*, 2018; Jørgensen *et al.*, 2009); tailoring hunting or fishing regulations, such as maximum or minimum allowable sizes, can reduce the evolution of smaller body size and earlier reproduction (Dunlop *et al.*, 2009). As another example, moving individuals with beneficial genotypes between populations can facilitate rapid adaptation to new climate conditions (i.e., assisted gene flow: Aitken & Whitlock, 2013; McLachlan *et al.*, 2007).

Policy decisions that influence rapid evolution can also be used to reduce the impact of harmful species, such as pest or pathogens. For instance, the rapid evolution of antibiotic resistance in many bacterial pathogens, and the rapid evolution of pesticide- and GMO-crop resistance in many crop pests, have been identified as major threats to human wellbeing (Carroll *et al.*, 2014; World Economic Forum, 2018). Hence, evolutionarily-informed policies have been used to slow the evolution of resistance (Carroll *et al.*, 2014; Tabashnik *et al.*, 2008); e.g., "refuges" – areas not planted with GMO crops or not sprayed with insecticides – are routinely used to prevent the evolution of resistance by insect pests to GMO crops or insecticides (Carrière *et al.*, 2010; Tabashnik *et al.*, 2008). Similarly, control of mosquitoes has been severely hampered by their evolution of pesticide-resistance, leading to the development of control strategies that are evolution-resistant (Read *et al.*, 2009) or that also make use of evolution: for instance, 'gene drive' can cause the rapid evolution of phenotypes that have much lower (rather than higher) fitness, and thus may disrupt mosquito reproduction or malarial transmission (Eckhoff *et al.*, 2016).

The following publications contain more details (Kok *et al.*, 2018; PBL, 2012, 2014; van Vuuren *et al.*, 2015; Visconti *et al.*, 2016), and there is discussion about their regional results in each IPBES regional assessment.

The widespread trait-mediated effects of drivers have caused dramatic shifts in organismal trait distributions (means and variances), though few global indicators are yet available **(Figure 2.2.18)**. The *Marine Trophic Index*, which reflects the average trophic level of fish caught within multiple regions, has fallen from around 4.0 to around 3.6 in the last 60 years, because fishing preferentially removes larger, more predatory fish (Pauly *et al.*, 1998): the proportion of global fish biomass that is made up of predatory fish has declined by a factor of around 10 since

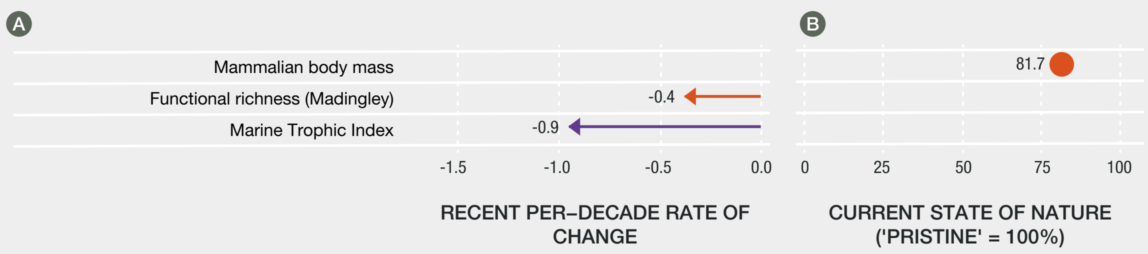


Figure 2 2 18 **Global indicators of species traits.**

Marine indicators are in purple, terrestrial in orange. A Trends, shown as the average per-decade rate of change since 1970 (or since the earliest post-1970 year for which data are available), ordered by rate of change. B Estimated current status relative to a pristine or at least largely pre-industrial baseline. No indicators provide both trend and status. See Supplementary Material S 2.2.9 for detailed information on each indicator.

1880 (Christensen *et al.*, 2014). The declining size of harvested individuals can reduce fishery productivity (Dunlop *et al.*, 2015). On land, the median *mammalian body mass* of species within 1° grid cells has fallen by 18% (Santini *et al.*, 2017), while a general ecosystem model (Harfoot *et al.*, 2014) estimates that *functional richness* within 0.5° grid cells is falling worldwide.

Changes in trait means can have important consequences for population dynamics, community structure, ecosystem functioning, and, more generally, nature's contributions to people. For example, the widespread declines of large species are already profound affecting many ecosystem functions at sea and on land (Dirzo *et al.*, 2014; McCauley *et al.*, 2015; Ripple *et al.*, 2014). Extinct terrestrial megafauna maintained a degree of openness in forest structure, giving landscapes high habitat diversity; their loss has led to more forest canopy closure and has also changed fire regimes (Johnson, 2009), greatly reduced long-distance dispersal of many fruits (Pires *et al.*, 2018) and dispersal of productivity-limiting nutrients (Doughty *et al.*, 2013), as well as affecting many other ecosystem processes (Ripple *et al.*, 2015). Likewise, the historical and ongoing loss of large species from oceans has reduced connectivity among ecosystems and reduced their temporal stability (McCauley *et al.*, 2015).

Changes in trait diversity are important as well as changes in mean values, because the assemblage-level diversity in how populations respond to drivers of change underpins ecosystem stability and resilience under drivers of change (Diaz & Cabido, 2001; Elmqvist *et al.*, 2003). For instance, both among- and within-population diversity in adaptive life history traits in salmon tend to stabilize temporal variation in overall abundance and hence harvest (Schindler *et al.*, 2013). Similarly, different plant genotypes have different effects on arthropod communities, soil microbial communities, decomposition rates, nutrient cycling, and nitrogen mineralization (Bailey *et al.*, 2009).

Knowledge gaps: Few global indicators synthesize changes over time in organismal traits across large numbers of species, and none that does so for trait-based estimates of functional diversity, despite its ecological importance.

2.2.5.2.6 Genetic composition

Within-population genetic diversity has been lost at the rate of about 1% per decade since the mid-19th century, according to the only global meta-analysis (76 studies of 69 species; Leigh *et al.*, 2018). Island populations in

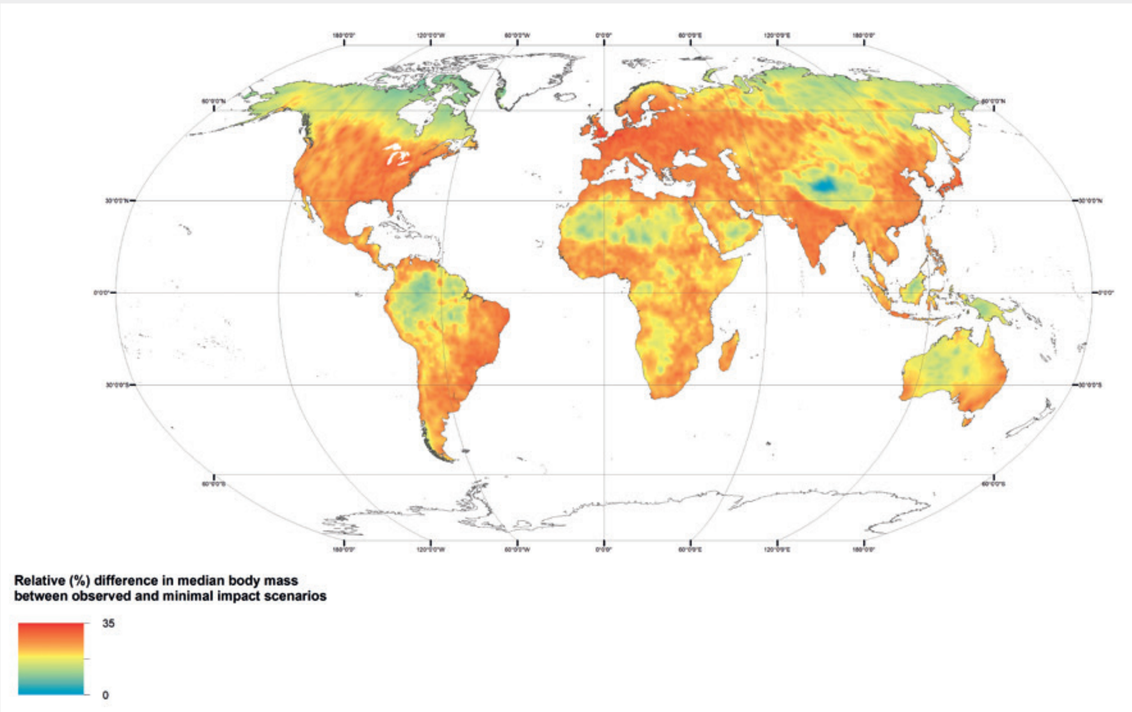


Figure 2.2.19 **Geographic variation in the percentage reduction in median mammalian body mass as a result of species range loss caused by human impacts.**

Data from Santini *et al.* (2017).

the survey tended to have lost more genetic diversity than mainland populations: those from Mauritius and the Seychelles have lost an average of 49% of their genetic diversity (Leigh *et al.*, 2018). Support for a general human-caused decline comes from a map showing that within-species genetic diversity of amphibians and mammals tends to be lower in areas with greater human influences, especially urban areas, other settlements, and croplands (Miraldo *et al.*, 2016; see **Figure 2.2.2F** in Section 2.2.3.1). A synthesis comparing genetic diversity estimates from wild populations facing different direct drivers found that populations whose habitat had been fragmented by land-use change have around 17% less genetic diversity than undisturbed populations (DiBattista, 2008); that study found no effect of direct exploitation on genetic diversity, but another meta-analysis reported that populations of fish species that have been overfished in the last 50 years had significantly lower genetic diversity than populations of closely related species (Pinsky & Palumbi, 2014). The declines in range size, numbers of populations, and population sizes of many species (Section 2.2.5.2.4) will all tend to reduce their genetic diversity (Frankham, 1996).

Many farmed and domesticated plants and animals have lost genetic diversity through the extinction of races and varieties. By 2016, 559 of the 6190 domesticated breeds of mammal were recorded as extinct (including 182 breeds of cattle, 160 of sheep and 108 of pig), as well as 84 of the 2632 domesticated breeds of bird (including 62 chicken breeds and 15 breeds of duck) (FAO, 2016b). A further 1500 breeds (999 mammals and 501 birds) are currently threatened with extinction (FAO, 2016b). These numbers are sure to be underestimates as the conservation status of 58% of breeds remains unknown (FAO, 2016b). Modernization of agriculture has sharply reduced both the numbers of crop species and numbers of varieties of those species that are cultivated (Esquinas-Alcázar, 2005).

Losses of genetic variation can be permanent, or nearly so, because the forces that deplete variation (extinction, small population size, inbreeding, natural selection) typically work much more quickly than do the forces replenishing variation (speciation, mutation, recombination, gene flow). For example, the cheetah (*Acinonyx jubatus*) still shows genetic evidence of a population bottleneck around 12,000 years ago, around the same time that many other large mammals were extirpated from the area (Dobrynin *et al.*, 2015). Similarly, hunting and land-use change have extirpated many genetically unique populations of the black rhinoceros (*Diceros bicornis*), with the loss of over two thirds of its historical mitochondrial genetic variation (Moodley *et al.*, 2017); and the fur seal (*Arctocephalus gazella*) still has little among-population genetic variation after the commercial sealing in the 18th and 19th centuries caused populations to crash (Wynen *et al.*, 2000).

Direct drivers have commonly been shown to reduce phylogenetic diversity (PD: Faith, 1992), a measure of genetic diversity among species. In the Brazilian Caatinga, plant communities in sites that have undergone more disturbance (e.g., selective logging, fuelwood extraction and grazing) have lower PD than communities in less disturbed sites (Ribeiro *et al.*, 2016). Costa Rican bird communities living on intensively farmed land have 900 million years less PD than those in natural forest, and 600 million years less than those on diversified agricultural land (Frishkoff *et al.*, 2014). Worldwide, bird assemblages in highly urbanized habitats average 450 million years less PD than those in natural habitats nearby, mainly because of local extinctions (Sol *et al.*, 2017). In some contexts, gains in PD from alien species has outweighed the PD losses from local extinctions, as in Pacific Oceanic island assemblages of flowering plants (Carvallo & Castro, 2017).

Knowledge gaps: Global synthesis of patterns and trends in genetic composition is still at an early stage, with analyses so far having limited taxonomic or geographic coverage.

2.2.5.3 Status and trends of nature in land and sea managed and/or held by Indigenous Peoples and Local Communities

2.2.5.3.1 Status and trends of nature as assessed by science

(N.B. Italics denote indicators that are plotted, for indigenous lands and for the world as a whole, in **Figures 2.2.8** or **2.2.13**)

Indigenous lands have ecosystems that are more structurally intact, and ecological communities that are more compositionally intact, than the global average for terrestrial regions; and their intactness is declining more slowly. Around half of the indigenous land mapped by Garnett *et al.* (2018) is still *primary vegetation*, compared with a global average of only 39% (Hurtt *et al.*, 2018); only 7% is cultivated or urban (global average = 24%) (ESA, 2017); and two thirds is classed as 'natural' (Human Footprint score < 4), compared with only 44% of other lands (Garnett *et al.*, 2018). The *Biodiversity Intactness Index* (BII) (Hill *et al.*, 2018) averages 85% on indigenous lands (versus 79% globally); a more fine-grained of BII estimate for tropical and subtropical forest biomes (*tropical forest BII*) (De Palma *et al.*, 2018) gives a lower estimate for average BII in indigenous lands (68%), but still higher than the global average for these biomes (62%); and *Mean Species Abundance* averages 85.5% in Indigenous Lands (versus

76.1% globally). These indicators also tend to be declining markedly more slowly in indigenous lands than across the globe as a whole (at 33% of the global rate for the loss of *land that is not cultivated or urban*, and 68% of the global rate of loss of *tropical forest BII*).

Many of the worlds' healthiest ecosystems, and a significant proportion (and in many regions the majority) of natural land outside protected areas, are within IPLC lands (Garnett *et al.*, 2018; Porter-Bolland *et al.*, 2012). Several studies indicate that IPLCs reduce deforestation rates (e.g., Genin *et al.*, 2013; Porter-Bolland *et al.*, 2012). However, to date there is not enough evidence for the conservation advantages of community-based forest management, and more quantitative case studies are needed to demonstrate causal relationships (Bowler *et al.*, 2010; Rasolofoson *et al.*, 2015).

No global analysis of agrodiversity trends on IPLC lands is yet available, but some biodiversity-rich lands (e.g., under shifting cultivation) have been converted to large-scale industrial food and biofuel production (Heinimann *et al.*, 2017); and global trade increases the land area under cash-crop cultivation, decreasing local crop diversity, and pushing people to deforest, make a living on marginal areas or overexploit local biodiversity (Wolff *et al.*, 2017). Nonetheless, lands managed and held by IPLCs have often kept, despite agricultural modernization, a high diversity of genetic resources such as adaptive varieties and breeds (Jarvis *et al.*, 2008).

2.2.5.3.2 Trends of nature as observed by Indigenous Peoples and Local Communities

IPLCs often monitor changes not only of their key natural resources but also of other salient features of nature at the population, ecosystem and landscape levels, giving them a deep understanding of multi-decadal trends in nature (Sterling *et al.*, 2017). For example, IPLCs will often closely monitor introduced species that significantly affect natural resources important for them (e.g., Aigo & Ladio, 2016; Lyver *et al.*, 2017; Periago *et al.*, 2017), often before they become sufficiently widespread to attract the attention of natural scientists. Culturally, ecologically or morphologically salient (cf. Hunn, 1991) species are often monitored closely as well (Fernández-Llamazares *et al.*, 2016; Giglio *et al.*, 2015; Lykke, 2000). Pastoralists frequently mention trends of populations of palatable or unpalatable species; e.g., in Europe (Fernández-Giménez & Estaque., 2012; Molnár *et al.*, 2017); in Asia (Behmanesh *et al.*, 2016; Bruegger *et al.*, 2014; Hopping *et al.*, 2016; Kakinuma *et al.*, 2014); in Africa (Admasu *et al.*, 2010; Angassa & Beyene, 2003; Assefa & Hans-Rudolf, 2016; Oba & Kaitira, 2006; Oba & Kotile, 2001). Ecological indicators developed and used by IPLCs are often biocultural, having both social and cultural dimensions (Sterling *et al.*, 2017). Some of these indicators are compatible with indicators used by scientists such as those related to species composition, vegetation structure and phenological traits (cf. Danielsen *et al.*, 2014; Harmsworth *et al.*, 2011; Nursey-Bray & Arabana Aboriginal,

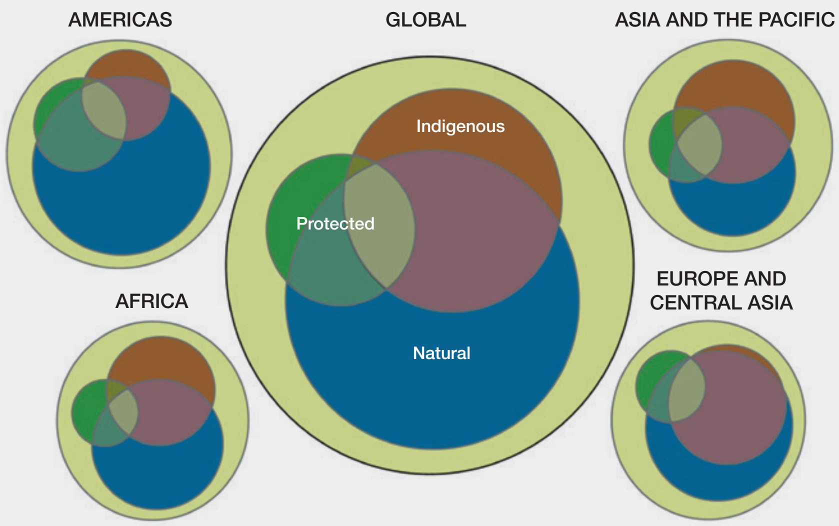


Figure 2 2 20 **Intersections among indigenous lands, protected areas and natural (Human Footprint score < 4) landscapes (see following sections) globally and for each IPBES region.**

Circles and intersections are all proportional to area with the largest circle scaled to the land area of the Earth (excluding Antarctica) (Garnett *et al.*, 2018).

2015). Other indicators, typically those with deeper social and cultural meaning, are less compatible. The selection of elements of nature monitored by IPLCs may be influenced by conservation and national policies (TEBTEBBA Foundation, 2008).

Of the approximately 470 indicators and related 321 trend records reported in the reviewed literature, 72% showed negative trends **(Figure 2.2.21)**. Many of these (e.g., negative trends of species populations – 27.6%, negatively perceived trends regarding species composition change – 9.5%) are connected directly or indirectly to changes in nature's contributions to people that make living from nature more difficult for IPLCs **(Figure 2.2.21B)**. The indicators are distributed unevenly among the unit of analysis, but over half the trends are negative except in tundra habitats **(Figure 2.2.21A)**.

The main global trends were as follows:

- Resource availability is generally decreasing, whereas time needed or distance travelled to harvest resources is increasing (e.g., Lyver *et al.*, 2017; Posey, 1999), especially in boreal forest and tundra habitats where distribution and abundance of salient game species is changing due to climate change (Fienup-Riordan *et al.*, 2013; Huntington *et al.*, 2016; Naves, 2015).

- Declines or increases in wild species populations are among the most common indicators in almost every unit of analysis (26.6%, but 32.8% if indicators about their accessibility is also included), with culturally salient species often showing negative population trends (mainly plants, mammals, birds, fishes and insects, e.g., Aswani *et al.*, 2015; Bruegger *et al.*, 2014; Cuerrier *et al.*, 2015; Reis-Filho *et al.*, 2016; Reyes-García *et al.*, 2016).

- IPLCs have observed many native newcomer species arriving to their area as climate changes (e.g., southern species to boreal/arctic areas), but also the arrival and spread of new pests and aggressive alien species (e.g., Aigo & Ladio, 2016; Cuerrier *et al.*, 2015; Jandreau & Berkes, 2016; Lyver *et al.*, 2017).

- IPLC indicators recognize an increase in natural habitat loss, especially forests and grazing lands (e.g., Admasu *et al.*, 2010; Ancrenaz *et al.*, 2007; Calvo-Iglesias *et al.*, 2006; Jandreau & Berkes, 2016; Kimiti *et al.*, 2016; Turner & Clifton, 2009), while remnant ecosystems appear to be degrading and their biomass production decreasing (e.g., opening up of forest canopy; less biomass, more annuals and shrubs on pastures; proportion of unpalatable plants on rangelands; e.g., Admasu *et al.*, 2010; Angassa & Beyene, 2003; Assefa & Hans-Rudolf, 2016; Behmanesh *et al.*, 2016; Bruegger *et al.*, 2014; Jandreau & Berkes, 2016)).

- IPLCs have observed that the condition of wild animals appears to be deteriorating and their sizes decreasing (e.g., Giglio *et al.*, 2015; Huntington *et al.*, 2016; Moller *et al.*, 2004; Naves, 2015; Parlee *et al.*, 2014; Wong & Murphy, 2016)).

Box 2 6 Indicators of nature used by Indigenous Peoples and Local Communities.

Unlike many scientific indicators that try to maximize broad comparability and therefore try not to be influenced by local context, IPLC indicators are often more closely linked to human-nature relations (Sterling *et al.*, 2017) and are holistic in nature (Berkes, 2012; Inuit Circumpolar Council, 2015; Posey, 1999). Many IPLC indicators are locally tested, are intended to be locally relevant (TEBTEBBA Foundation, 2008), and go back for decades (Huntington *et al.*, 2005; Mantyka-Pringle *et al.*, 2017; Turner & Clifton, 2009). IPLCs, with a longer baseline of personal experience with the environment, may be more aware of shifts in nature (cf. changes in the Arctic, the bias in monitoring protected area management effectiveness; Corrigan *et al.*, 2018). Some cultural memories go back hundreds or even thousands of years (Nunn & Reid, 2016). Furthermore, local observations may cover many less studied, remote habitats and regions that often present environmental or technical inconveniences for scientists (Fienup-Riordan *et al.*, 2013; Huntington *et al.*, 2005). Finally, local monitoring systems are often independent from formal projects and financial limitations.

However, IPLCs monitoring data also have drawbacks for regional and global assessments. Notably, they are often non-quantitative and follow a fuzzy logic (Berkes & Berkes, 2009; Reyes-García *et al.*, 2016) so are less compatible with scientific monitoring protocols. Data on local trends are scattered among thousands of Indigenous Peoples and Local Communities, and the diverse sets of locally adapted indicators are even more difficult to synthesize globally than scientific data. IPLCs and scientific data, however, may often efficiently complement each other in helping to understand local impacts of global changes (Huntington *et al.*, 2005; Reyes-García *et al.*, 2016; Turner & Clifton, 2009).

A more detailed global synthesis of IPLC-observed trends in nature is hindered by the inherent challenges in this process, such as obtaining properly acquired Free, Prior and Informed consent (FPIC), the time required for adhering to local community protocols, and the lack of centralized institutions for hosting, aggregating and analyzing data of IPLCs in culturally appropriate ways.

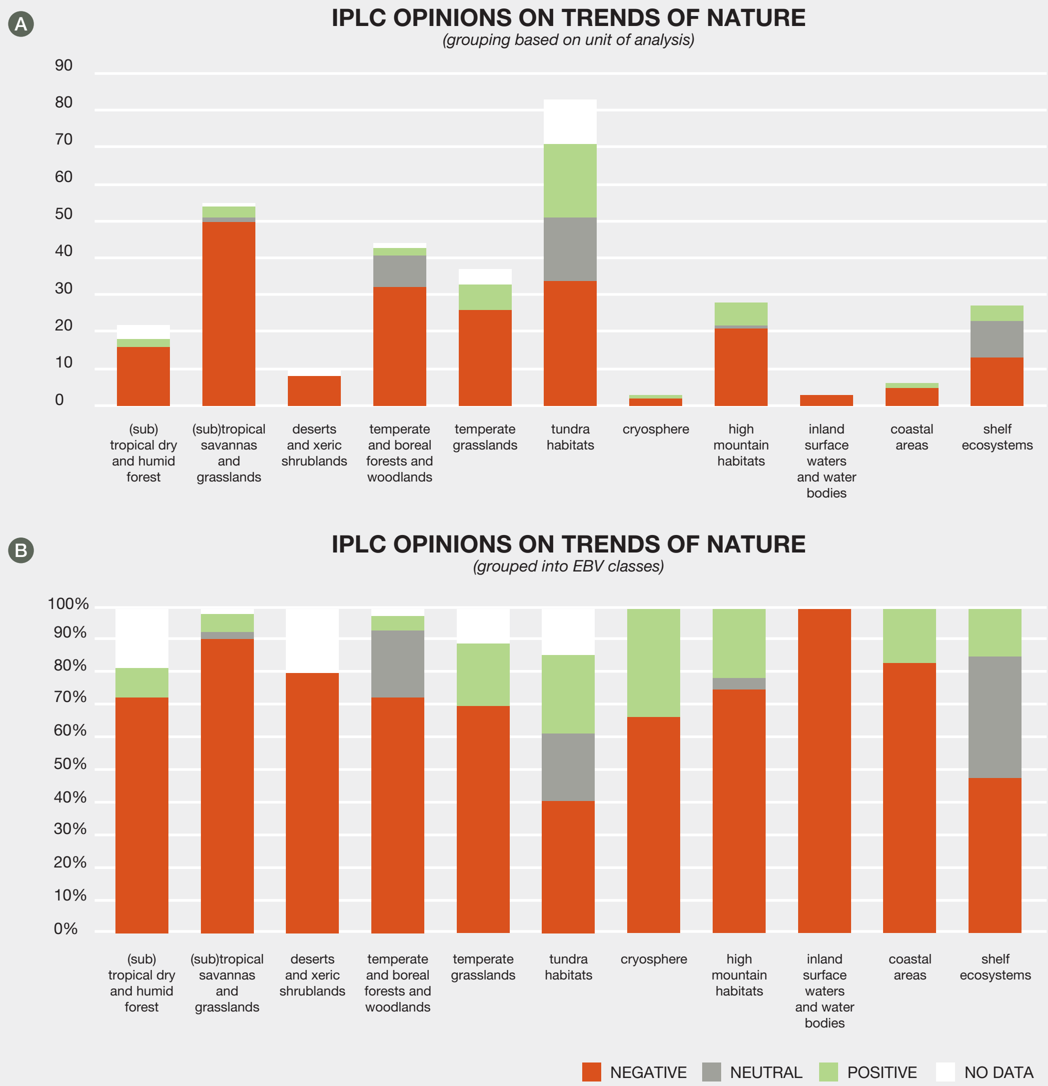


Figure 2 2 21 **Opinions on trends in nature as assessed by Indigenous Peoples and Local Communities using their own indicators, split into A main ecosystem types (mostly unit of analysis), and B per Essential Biodiversity Variable class.**

The analysis is based on 321 trend records published in 54 publications found in a systematic review (see Supplementary Material). No data was found on genetic diversity of wild species. Opinions, whether the trends impact IPLCs in a positive, neutral or negative way, were based on local understandings of the trend, but only if it was explicitly documented in the sources. No data: no opinions on trends were provided by the publication. (Source: IPBES)

2.2.6 GLOBAL-SCALE ANALYSIS OF ATTRIBUTION OF TRENDS TO DRIVERS

2.2.6.1 Challenges of synthesis

This section focuses on attributing temporal changes in the state of nature to the set of direct drivers described in Sections 2.1.13–2.1.17 in chapter 2.1, and the findings presented below are based on two extensive systematic reviews. The first (see Supplementary Material, Appendix AA for methodology) is a synthesis of natural science studies that have assessed and compared the impacts of at least two direct drivers on indicators reflecting the state of nature. This synthesis examined nearly 4000 studies and databases identified as potentially relevant, retaining 163 priority non-redundant sources (listed in Supplementary Material, Appendix BB); priority was given to large-scale studies (preferably global, but also continental or regional ones), but local studies were used when no large-scale studies were available. The second synthesis (see Supplementary Materials, Appendix CC for methodology) examined how IPLCs attribute trends in nature to direct drivers. This examined 6,136 studies, retaining 192 for analysis (see details in Appendix CC). Studies were excluded from this IPLC-focused synthesis if they focused only on science-based indicators or considered community-based monitoring programmes without using locally developed indicators. The two syntheses therefore use extensive but complementary evidence bases.

Synthesizing the attribution of changes in the state of nature to direct drivers is not straightforward. The complexity and high dimensionality of nature (Section 2.2.3) mean that many indicators are needed to capture trends (Sections 2.2.3 and 2.2.5); but indicators can differ in their metrics, sampling methods, spatial and temporal scales and resolutions, taxonomic groups, realms and regions (Section 2.2.5). These syntheses therefore organize indicators using the same Essential Biodiversity Variable (EBV: Pereira *et al.*, 2013) framework as used in Sections 2.2.3 and 2.2.5, aggregating information across multiple indicators within each EBV class for robustness and generality. Specific patterns are reported for some indicators having sufficient reliable information.

There are a range of ways of comparing the importance of different drivers. For example, prevalence-based attribution can be used with IUCN Red List assessments, estimating the commonness of each driver among the listed threats (e.g., Salafsky *et al.*, 2008; Vié *et al.*, 2009). By contrast, Mean Species Abundance (MSA; Alkemade *et al.*, 2009) lends itself to effect-based attribution, because it is estimated by combining independent driver-specific dose-response models with global data on driver pressure intensity. These two approaches are in principle not directly comparable because, e.g., a driver could affect all of a set of species without being the strongest threat to any. In order to include as wide a range of studies as possible, these syntheses have assumed prevalence-based attribution to be a reasonable approximation of effect-based attribution.

Another challenge is that studies often use threat classifications that differ from each other and from the one used in this assessment. As far as possible, threats reported in the literature were allocated to one of the five major direct drivers used in this assessment (chapter 2.1 Sections 2.1.13–2.1.17); an additional category, 'Other', was used for threats that do not fit clearly into these categories, such as fire or direct human disturbances due to recreational activities.

Many studies ranked the importance of drivers instead of assessing their importance in terms of relative magnitude. Provided that the threat classification system is a good match to the one used here, this qualitative information was used and converted into quantitative estimates using a systematic approach (Hosonuma *et al.*, 2012; see details in Appendix AA).

Although IPLCs usually possess a deep understanding of the impact of direct drivers on nature due to their closeness and direct dependence on nature for their livelihoods (Luz *et al.*, 2017; Reyes-García *et al.*, 2014), combining IPLC-observed driver information with natural science data presents additional problems. IPLC attribution is typically less quantitative, more scattered (geographically and thematically), and harder to aggregate globally; but provides unique insight into how drivers affect aspects of nature directly related to local livelihoods.

Section 2.2.6.2 presents the relative impacts of the different direct drivers on changes in different aspects of nature at the global level, for each of the four IPBES regions (Americas, Europe and Central Asia, Africa and Asia and the Pacific) and for each of the three global biogeographic realms (i.e., terrestrial, freshwater and marine), based on natural science indicators **(Figure 2.2.22)**. The attributions of drivers by units of analysis are not presented here, mainly because many of the indicators considered do not have information broken down at that level. Moreover, the amount of information collected does not allow for a sufficiently robust analysis such as that presented at the level of regions and realms. Therefore, attributions of drivers within each units of analysis are described in Section 2.2.7 on the basis of relevant and comprehensive bibliographic references compiled by the authors. Section 2.2.6.3 then synthesizes the perceptions of IPLCs about the drivers behind changes in local IPLC indicators within different types of ecosystems.

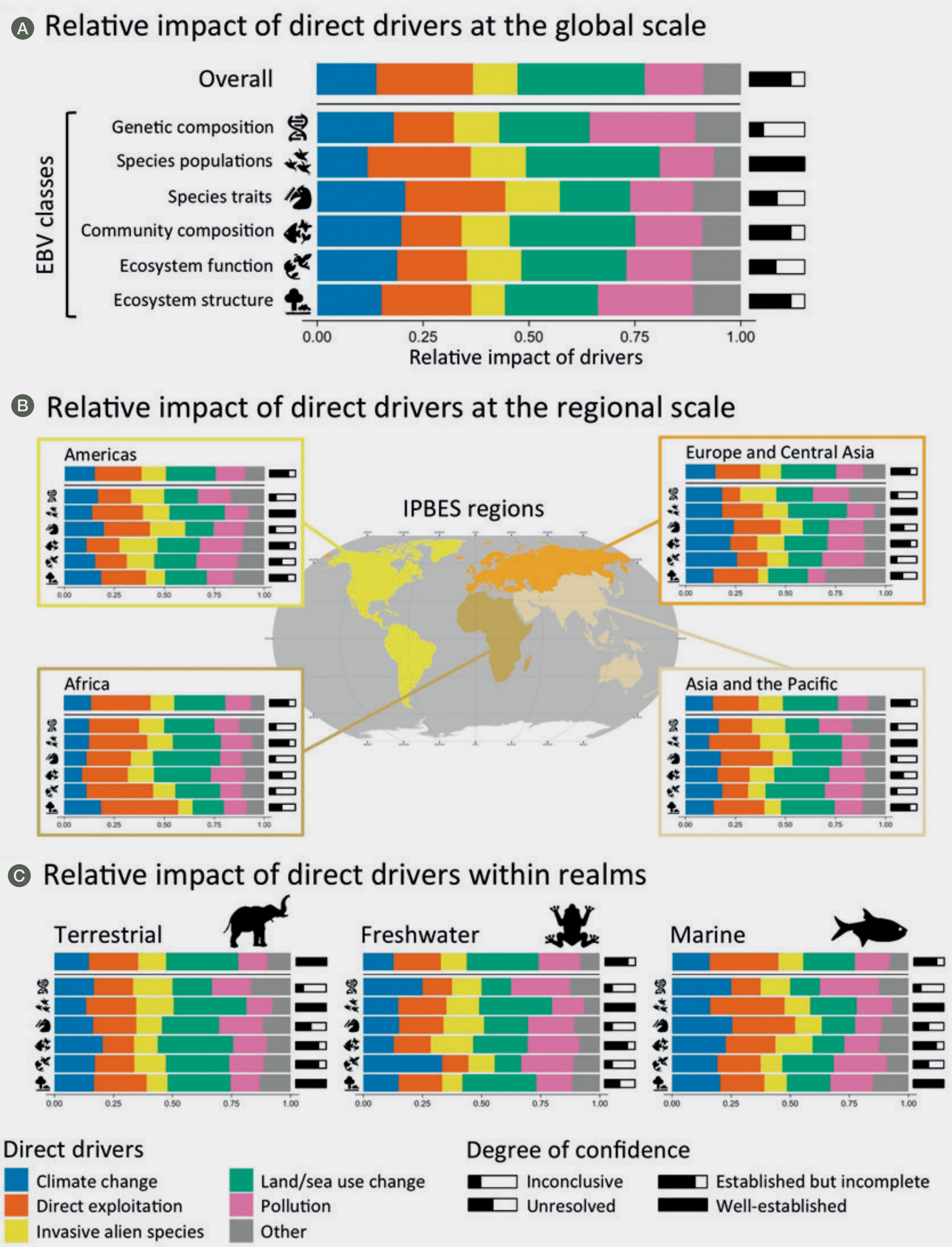


Figure 2 2 22 **Relative impact of direct anthropogenic drivers (colour bars) on the state of nature at the global scale A, within each IPBES region B and for terrestrial, freshwater and marine realms C.**

The top row in each panel shows the overall pattern including all the indicators used in the analysis. The next rows show the patterns for each of the six classes of Essential Biodiversity Variables (EBV), each represented by several indicators. The width of each colour bar indicates the estimated relative importance of each driver in changing the state of nature but should not be interpreted as an absolute magnitude of the impact of each driver because both qualitative and quantitative information was combined in the analysis (see details in the main text). The degree of confidence shown alongside each row (more black = more confidence) reflects the quantity and quality of information available in the literature to estimate the relative impact of different drivers at the corresponding level of analysis (see confidence framework in chapter 1). Note that the top row in each panel is not a simple average across the different EBV classes: some classes include more indicators and/or more studies than other classes (see degree of confidence) so have a higher weight in the estimations. A full list of studies synthesized in this figure is provided in Appendix BB, and the methodology is described fully in Appendix AA. Credits for icons: EBV classes icons created by Cesar Gutiérrez of the Humboldt Institute –Bogotá, Colombia- for GEO BON; icons for realms provided by WWF.

The relative global importance of direct drivers also varies among indicators within EBV classes, as shown in **Figure 2.2.23** for a set of specific indicators for which sufficient information was available. Further discussion on these indicators is presented in Appendix DD.

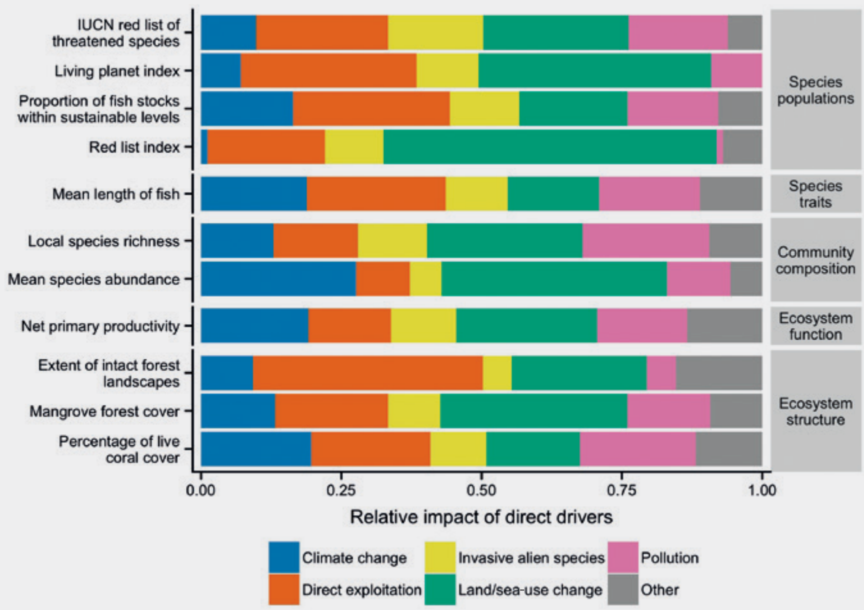


Figure 2 2 23 **Relative impact of direct anthropogenic biophysical drivers (colour bars) on selected indicators of the state of nature for which sufficient representative information was available.**

Indicators are grouped according to the Essential Biodiversity Variable (EBV) framework (see right-hand side), except that no indicators were available for the EBV class *Genetic composition*. The driver category "Other" includes threats that do not clearly belong to any of the five main drivers (e.g. fire, human disturbance, recreational activities, and tourism). The width of each colour bar indicates each driver's estimated relative importance in changing the state of nature (see details in the main text and in **Figure 2.2.22**). Further discussion on these individual indicators is included in Appendix DD.

2.2.6.2 Attribution of natural science indicator trends to direct drivers

Land/sea-use change is the most important direct anthropogenic driver of change in the global state of nature, with a relative impact of 30%, followed by direct exploitation (23%), climate change (14%), pollution (14%) and invasive alien species (11%) **(Figure 2.2.22A)**. Threats not clearly aligned to any of these five main drivers (e.g., fire, human disturbance, recreational activities, and tourism) account for the remaining 9%.

The relative global importance of drivers varies considerably among the five EBV classes where robust comparisons could be made (too few studies assessed the relative impact of drivers of change in *Genetic composition* for comparisons to be robust) **(Figure 2.2.22A)**. Land/sea-use change is the most important driver of change for three of the five remaining EBV classes and is particularly important for *Species populations* (31.5%). Pollution is very slightly more important than land/sea-use change (22.5% versus 22%) in driving changes in *Ecosystem structure* but is not in the top two drivers for other EBV classes. Direct exploitation is the most important driver of changes in *Species traits* (23.5%), with climate change second (21%). Climate change is also second for *Community composition* and *Ecosystem function*.

The four IPBES regions largely reflect the global pattern **(Figure 2.2.22B)**, but there are some regional differences. In

Africa, the impact of direct exploitation (30%) exceeds that of land/sea-use change (25.5%). In the Americas, these two drivers have a similar impact (23.5 and 25%, respectively). In the other two regions, land/sea-use change is the most important driver of change in the state of nature.

Each IPBES region shows considerable variation among EBV classes. For example, direct exploitation has the highest impact on *Ecosystem structure* in Africa, whereas other threats (i.e., fires) are particularly important in Europe and Central Asia **(Figure 2.2.22B)**. Although climate change is not the dominant driver across EBV classes in any of the IPBES regions, it has a particularly high impact on *Species traits*, *Community composition,* and *Ecosystem function* in Europe and Central Asia.

Land-use change has had the largest relative negative impact on nature in the terrestrial and freshwater realms (30.5% in both cases), mainly through habitat loss and degradation, whereas in marine ecosystems, direct exploitation of organisms (mainly fishing) has had the largest relative impact (29%) **(Figure 2.2.22C)**. Direct exploitation is the second most important driver in both terrestrial (21%) and freshwater (20%) ecosystems. Climate change is not amongst the two most important drivers of change in any of the realms. In freshwater environments, pollution (17.5%) is more important than climate change (13%) whereas these two drivers have a similar impact (15% and 16%, respectively) in marine systems.

Within each realm there is considerable variation among EBV classes **(Figure 2.2.22C)**. In terrestrial ecosystems, the greatest impact of land/sea-use change is on *Species populations* (31%) and *Community composition* (32%). In freshwater ecosystems, this driver particularly affects *Species populations* and *Ecosystem structure* (both 31%). For marine ecosystems, the highest impact of direct exploitation is on *Species populations* (31.5%). Climate change's strongest impact on land is on *Community composition* (20%); in freshwater it is on *Ecosystem function* (33%) (but with a low degree of confidence); and in the marine realm it most affects *Species traits* (25.5%). Even if their overall importance is limited in all the realms, invasive alien species are markedly impacting some aspects of biodiversity, such as *Community composition* in freshwater ecosystems (18%).

2.2.6.3 Attribution of drivers by Indigenous Peoples and Local Communities

The two most important drivers of changes in nature observed by IPLCs are land/sea-use change and climate change **(Figure 2.2.24)**. Land-use change includes mainly conversion to intensive agriculture, urbanization and discontinuation of traditional land management practices. For example, land-use change and expansion

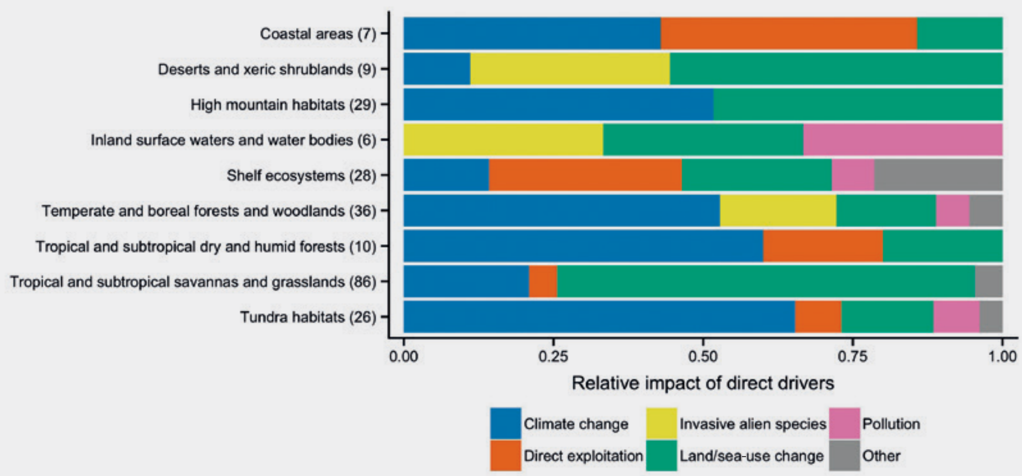


Figure 2 2 24 **Attribution of changes in different ecosystems (rows) to direct drivers (colour bars) compiled from IPLC observations worldwide based on 470 reviewed local IPLC indicators (see Appendix CC).**

Numbers in brackets are numbers of indicators with driver attribution. Relative impact of direct drivers is shown as their relative frequency in the reviewed studies. The category "other" includes threats that were identified for some ecosystems during the collection of data but are not clearly linked to the five main categories (e.g. vegetation encroachment, disease and insect outbreaks).

of settlements (urbanization) are the direct drivers of change in rangelands most often mentioned by IPLCs in a number of African regions (Admasu *et al.*, 2010; Assefa & Hans-Rudolf, 2016; Jandreau & Berkes, 2016; Kimiti *et al.*, 2016).

Discontinued traditional land management practices (abandonment) were observed as direct causes for some changes to vegetation structure (e.g., bush encroachment, reforestation; Babai *et al.*, 2014; Oba & Kotile, 2001; von Glasenapp & Thornton, 2011). Climatic changes, such as droughts and the increasingly unpredictable annual distribution of rainfalls, are important observed reasons for the decreasing biomass production and changes in vegetation structure of rangelands, which often require reorganization of traditional grazing regimes (e.g., Admasu *et al.*, 2010; Assefa & Hans-Rudolf, 2016; Duenn *et al.*, 2017; Kakinuma *et al.*, 2008). Altered rainfall patterns, which can influence behaviour patterns of wild animals (e.g., game or migration patterns of birds; Ingty, 2017; Kimiti *et al.*, 2016; MacDonald *et al.*, 2013; Turner & Clifton, 2009), are also seen as important drivers of change.

Deliberate or unintentional introduction of new species can also be direct drivers of changing species pools in different habitats (e.g., inland water bodies, wetlands; Aigo & Ladio, 2016; terrestrial habitats: Lyver *et al.*, 2017; Periago *et al.*, 2017). IPLCs report invasive alien species affecting a wide range of taxonomic groups (e.g., plants, fishes, birds; Aigo & Ladio, 2016; Lyver *et al.*, 2017; Periago *et al.*, 2017; Waudby *et al.*, 2012). Overexploitation was the most often reported driver for deterioration of pasture land and tropical forests at the agricultural frontiers (e.g., Aswani *et al.*, 2015; Fernández-Llamazares *et al.*, 2016). Local overharvesting by companies or by local fishers motivated by commercial trade were mentioned by artisanal fishers as drivers of observed decreasing fish stocks (Aswani *et al.*, 2015; Carr & Heyman, 2012; Giglio *et al.*, 2015; Reis-Filho *et al.*, 2016).

2.2.7 UNITS OF ANALYSIS

2.2.7.1 Introduction

The Units of Analysis for the Global Assessment are a broad-based classification system at the global level, considering both the state of nature in classes equivalent to biomes, and in anthropogenically-altered biomes or 'anthromes'. The units correspond broadly to global classifications of nature and human interactions, serving the need for analysis and communication in a global policy context. The list of 17 global Units of Analysis includes 13 biomes (7 terrestrial, 2 freshwater, 3 marine and one cuts across all three) and 4 anthromes (see chapter 1 and **Figure 2.2.2A**). All terrestrial biomes except for the cryosphere have been settled and populated by IPLCs historically, and increasingly by modern societies. The freshwater biomes reflect a simple split in relation to depth and vegetation, i.e., coarse function, and the marine biomes reflect the most basic division of oceans by depth and proximity to land. Nevertheless, the biomes reflect relatively well-known properties and variation in nature across the globe and coproduction of NCP by people. Biomes are the lungs, heart, production center, skin and kidneys of planet earth. They cycle carbon, nitrogen and other elements; provide food and materials; process waste.

The biomes vary in state from unaltered to highly altered or degraded. The addition of anthropogenic drivers of decline to natural disturbances can impose significant cumulative impacts on biomes, with complex interactions. Some biomes remain unmodified in only a small fraction of their former range; e.g., in most regions, nearly all temperate forest has been altered or is under active human management. There is considerable variation among and within regions, and among and within biomes. Some biomes have experienced positive changes recently, as land-use practices reverse; boreal forest area has been stable for decades, while temperate forest area has expanded 10% since 1990.

Anthromes are highly altered biomes, defined by humanity's monopolization and/or maximization of one or more NCP (i.e., distinct from degraded biomes). The main drivers of biome conversion to anthromes include large-scale commercial agriculture, local subsistence agriculture, urban expansion, construction and mining. The anthromes layer over biomes (e.g., a city in a grassland area), but some so transformed the original biome no longer exists there. Two anthromes are exclusively terrestrial, reflecting where people live and channel biological productivity to serve needs through food, timber and other types of production. In temperate biomes, conversion to anthromes and deterioration has slowed to zero or even reversed with active

Table 2 2 2 **Overview of some of the features on the IPBES Units of Analysis.**

Unit Name	Unit ID	Area (mSqKm)	NPP (gC/m2/ year x10^6)	Average Relative Species Richness	Population (millions of people)	Urban Areas (Unit 9)		Cultivated Areas (Unit 10)	
						mSqKm	% of unit	mSqKm	% of unit
Tropical and subtropical dry and humid forests	1	23.49	64	0.51	2,880	0.13	0.6%	6.83	29.1%
Temperate and boreal forests and woodlands	2	32.04	69	0.17	2,003	0.49	1.5%	7.75	24.2%
Mediterranean forests, woodlands, and scrub	3	3.22	5	0.20	314	0.06	1.8%	1.58	48.9%
Arctic and mountain tundra	4	13.55	12	0.09	169	0.01	0.1%	0.70	5.1%
Tropical and subtropical grasslands	5	20.18	26	0.35	655	0.03	0.2%	4.42	21.9%
Temperate Grasslands	6	11.19	14	0.20	363	0.10	0.9%	6.27	56.0%
Deserts and xeric shrublands	7	27.89	8	0.14	788	0.06	0.2%	2.18	7.8%
Cryosphere+	11	17.71 (22.59)			-	-	0.0%	-	0.0%
Subtotals (terrestrial)		***149.28***	***198***		***7,171***	***0.88***	***0.6%***	***29.72***	***19.9%***
Wetlands	8	NA							
Inland surface waters and water bodies	13	3.65	1	0.16					
Subtotals (inland & fresh waters)		***3.65***	***1.47***						
Shelf ecosystems	14	21.16	36	0.06					
Surface open ocean	15	336.63	152	0.04					
Deep Sea	16	*		*					
Subtotals (ocean)		***357.79***	***187***						
Urban and Semiurban Areas	9	0.88							
Cultivated Areas	10	29.72							
Aquaculture Areas	12	**							
Coastal areas intensively used by humans	17	**							
Subtotals (anthromes)		***30.60***	***-***						
TOTAL		***510.72***	***387***		***7,171***	***0.88***		***29.72***	

Notes:
Empty cells show where numbers are not applicable
All values are in 2015, unless otherwise noted.
+ Area of terrestrial cryosphere = 17.71 mSqKm. Arctic and Southern Ocean annual sea ice extent has averaged 22.59 mSqKm for the ten years from 2008–2017.
* Same as/included in Unit 15
** Units have no calculable area. There are no databases for aquaculture locations (terrestrial, freshwater and marine) from which area can be calculated. 'Intensely and multiple used coastline' is currently undefined in terms of area, as the coastline is a linear feature. Global datasets are also not available for estimating its length or area.

restoration. However, in tropical biomes, where both human population and economic growth are high, conversion rates are still high. The aquaculture and intensively developed coastline anthromes cut across terrestrial, freshwater and marine systems, and conversion of marine biomes to anthromes is at its early stages. Both aquaculture and the intensively/multiply used coastlines are likely at an early stage of acceleration (see descriptions below), and no datasets currently exist to estimate their area.

The attribution of drivers presented in this section are based on key references identified by the authors for each unit of analysis and is therefore different and complementary to that in Section 2.2.6, which shows attributions by IPBES regions and by realms based on a global-scale systematic review of literature.

2.2.7.2 Tropical and subtropical dry and humid forests

Tropical and subtropical forests cover about 52% of global forested land (FAO, 2015a; Keenan *et al.*, 2015), holding an aboveground carbon stock of 190–220 billion tons (Baccini *et al.*, 2012; Liu *et al.*, 2015; Saatchi *et al.*, 2011), representing about 70% of the carbon in forests globally (Yingchun *et al.*, 2012), and 35% of terrestrial GPP (Beer *et al.*, 2010). These ecosystems harbor the greatest biological diversity globally, containing for example the ten hotspots with the greatest total number of endemic higher terrestrial vertebrates (Mittermeier *et al.*, 2011, 2004) and the greatest number of threatened species.

This Unit plays a vital role in local to global climate regulation, through complex hydrological and biogeochemical dynamics, mainly of CO_2 and water vapor (Bonan, 2008). The Amazonian rainforest keeps the air humid for over 3,000 km inland (Salati *et al.*, 1979), and transpires twenty billion tons of water daily (Nobre, 2014).

Globally, tropical and subtropical forest area has declined from 1990–2015. All top ten countries reporting the greatest annual net loss of forest area for 2010–2015 belong to this Unit (FAO, 2015a). The rate of loss of tropical forests was 10.4 M ha yr^{-1} in the 1990s, slowing to 6.4 M ha y^{-1} in 2010–2015 (Keenan *et al.*, 2015). For subtropical forests these numbers were 0.4 M ha yr^{-1} and 0.0 M ha yr^{-1}, respectively. These averages mask high variance between regions, as well as within regions and countries, with highest losses in South America and Africa (Hansen *et al.*, 2013). For example, while Brazil showed a reduction in annual forest loss from 2000–2012, increases were measured in all other regions.

Land-use change is the main driver of forest loss in tropical and subtropical regions (FAO, 2016c; Meyfroidt & Lambin, 2011; Newbold *et al.*, 2014); other subdrivers vary in importance among and within regions (Boucher *et al.*, 2011; DeFries *et al.*, 2010; FAO, 2016c). Overall, the main cause of deforestation is large-scale commercial agriculture (e.g., cattle ranching, oil palm, soy, and cocoa) (40% of deforestation), followed by local subsistence agriculture (33%), urban expansion (10%), infrastructure (10%) and mining (7%) (FAO, 2016c; Hosonuma *et al.*, 2012). Forest degradation is driven mainly by timber and logging (58%), fuelwood/charcoal (27%), uncontrolled fires (10%), and urban expansion (5%). Recognition of IPLCs' territories helps buffer deforestation in the Amazon (Soares-Filho *et al.*, 2010), and local farmer communities can contribute to reforestation (Jacobi *et al.*, 2013).

Habitat loss and degradation are the main causes of reductions in species richness and abundance (Newbold *et al.*, 2014; WWF, 2016), while habitat conversion and harvesting are the main threats to Threatened plant species in tropical forests (Brummitt *et al.*, 2015). Main trends perceived by IPLCs include the loss (or introduction) of salient large mammals (e.g., elephant, peccary) (Ancrenaz *et al.*, 2007; Sahoo *et al.*, 2013) and the proliferation or collapse of plant species (e.g., medicinal plants; Fernández-Llamazares *et al.*, 2016).

Tropical and subtropical regions are projected to experience extreme climatic conditions earlier than other regions, such as boreal forests, tundra and taiga (Beaumont *et al.*, 2011). Extreme climate events in the last two decades (Chen *et al.*, 2010; Marengo *et al.*, 2013; Satyamurty *et al.*, 2013), interacting with other factors such as deforestation and fire, have caused large-scale long-lasting impacts on forest structure and function, affecting hydrological and carbon cycles (Davidson *et al.*, 2012; Qie *et al.*, 2017).

Positive trends in forest cover are reported in thirteen tropical and subtropical countries containing 6.4% of global tropical and subtropical forest area (Supplementary Material S2.2.2.4). These countries have transitioned from net forest loss to net gain, mainly driven by planted-forest expansion (FAO, 2016c; Keenan, 2015; Sloan & Sayer, 2015).

2.2.7.3 Boreal and temperate forests

Boreal and temperate forests comprise one third and a quarter of global forest cover, respectively (FAO, 2015a), covering 1.91 billion ha (FAO, 2015a). They experience a cold continental climate, with a growing season of <130 days (temperate) and >140 days (boreal). Boreal forests sustain a low richness of coniferous trees that withstand freezing and extended dormant periods, with two abundant deciduous genera. The temperate zone has many continental endemic deciduous species, with some common genera, such as pines. The boreal biome is primarily in Canada, Russia, and Scandinavia, while the temperate zone occurs in both hemispheres, on six continents. Highly productive temperate rainforests occur on the west coast of North America, Chile, New Zealand, and Australia.

Boreal forest area did not change between 1990 and 2015 (FAO, 2015a) and 43.8% of the remaining global "Intact Forest Landscapes" are boreal (Potapov *et al.*, 2008). Nearly two thirds of boreal forests are currently under management, mostly for timber (Gauthier *et al.*, 2015). Virtually all temperate forests in most regions of the world are managed; temperate China and Europe were largely deforested by the 1500s, many countries have lost > 90% of their forest cover (Kaplan *et al.*, 2009), and there are no large intact or primary forest areas (Krishnaswamy & Hanson, 1999). Temperate forests have increased by about 67 million ha since 1990, largely due to planting in China and farm abandonment globally (Campbell *et al.*, 2008; FAO, 2015a; Keenan *et al.*, 2015; Yin *et al.*, 2005), but young secondary forest is much less rich in biodiversity than primary forest. Over 350,000 km^2 of intact forest landscapes (i.e., large areas of forest or natural mosaic, free from evident signs of human disturbance) were lost from temperate and boreal forests between 2000 and 2013 (Potapov *et al.*, 2017), showing continuing deterioration in the condition of primary forest within this unit of analysis.

The boreal forest is the largest store of terrestrial carbon (Bradshaw & Warkentin, 2015; Gauthier *et al.*, 2015; Pan *et al.*, 2011), over 75% of which is in soil organic matter (Bradshaw & Warkentin, 2015; Rapalee *et al.*, 1998). Boreal forest has sequestered 0.5 Pg C/yr since 1990, accounting for 20% of the annual terrestrial forest carbon sink (Kurz *et al.*, 2013; Pan *et al.*, 2011), but not all boreal forests are sinks owing to increased fires and respiration due to climate change (Hadden & Grelle, 2017). Between 1990 and 2007 temperate forests have stored a net 0.72 Pg C/yr (Pan *et al.*, 2011).

Both biomes are highly susceptible to climate change (Settele *et al.*, 2014), increasing fire risk (Bradshaw *et al.*, 2009), in part because of low boreal productivity and high susceptibility of peat and permafrost soils. Other climate drivers include moisture stress, warmer temperatures, increased insect infestations, N deposition, and CO_2 fertilization (Kint *et al.*, 2012; Silva *et al.*, 2010). Drier, warmer boreal forests will store less carbon due to moisture stress (Ma *et al.*, 2012), becoming a net source of greenhouse gasses (Flannigan *et al.*, 2000, 2009; Kurz *et al.*, 2013), despite increased productivity in northern open taiga forests (Boucher *et al.*, 2017; Goldblum & Rigg., 2010). A warming climate may result in release of the huge carbon store in frozen boreal peat soils (Schaefer *et al.*, 2011). Projections suggest shifts in forest distribution, depending on dispersal ability among tree species (e.g., Soja *et al.*, 2007). Large areas in the boreal forests are inhabited by IPLCs in Eurasia and North America, who report changing animal population trends (e.g., increasing moose, decreasing caribou, decreasing bird species, e.g., geese) and changing migration patterns, due to climate change (Lyver *et al.*, 2017; MacDonald *et al.*, 2013).

Invasive species and diseases have become a major driver of tree mortality in some temperate forests (Adams *et al.*, 2012; Charru *et al.*, 2010), and diseases are a developing problem in plantations (e.g., Sanderson *et al.*, 2012). Some planted trees are invasive in temperate forests, e.g., *Acacia* (Lorenzo *et al.*, 2011; Yelenik *et al.*, 2004). Temperate regions have high numbers of threatened and endangered species, including >500 tree species (Oldfield *et al.*, 1998), and there have been extinctions, including passenger pigeon (*Ectopistes migratorius*). No boreal plant or animal species has gone extinct but there have been national-level extirpations.

2.2.7.4 Mediterranean forests, woodlands and scrub

Mediterranean forests, woodlands, fynbos and scrub are discontinuously spread in five continents and twenty-two countries (Dallman, 1998). They cover 4 million km^2 (2% of total land area) in Southern Europe and Northern Africa (Mediterranean Basin), South Africa (Western Cape), Northwestern America (e.g., California chaparral), Southern America (Chilean matorral), and Southern Australia. These regions harbour an extremely high diversity of species originating from almost all known biogeographic realms of the world including new landraces (Blondel *et al.*, 2010; de Cortes Sánchez-Mata & Tardío, 2016) and include five biodiversity hotspots of global importance (Mittermeier *et al.*, 2011; Myers *et al.*, 2000). Vegetation types are coniferous or (mostly evergreen) broadleaf forests and woodlands, savannas and grasslands, scrublands and mosaic landscapes, resulting from a strong interaction between heterogeneous environmental conditions and a long-lasting influence of human activities (Blondel, 2006). The Mediterranean biome has the second lowest level of land protection among terrestrial biomes (Hoekstra *et al.*, 2005) and is projected to experience the largest future proportional loss of biodiversity (Malcolm *et al.*, 2006; Sala *et al.*, 2000).

Mediterranean terrestrial ecosystems are highly sensitive to the combined effect of global change drivers and specific driving forces, including climate change, land-use transformations and fires (Barredo *et al.*, 2016; Templado, 2014; Valladares *et al.*, 2014). With the particular geology of Mediterranean systems, these changes have resulted in more frequent and intense fires, water scarcity, land degradation and habitat fragmentation. The unit is increasingly becoming vulnerable (Batllori *et al.*, 2013; Klausmeyer & Shaw, 2009) and future outcomes are difficult to predict (Doblas-Miranda *et al.*, 2017, 2015; Voltz *et al.*, 2018). Recent shifts in fire regime modify the composition of the vegetation (from coniferous forests to landscapes dominated by broadleaf trees, scrub and grasslands) and decrease its further resilience to fires (Gil-Tena *et al.*, 2016), with strong impacts on key NCP such as water supply, carbon storage and food production and a possible switch to a different kind of ecosystem. While Mediterranean forests provide various material NCP (Bugalho *et al.*, 2011), scrublands mostly provide non-material or regulating NCP (e.g., pollination, reduction of extreme wildfire hazard, key habitats for biodiversity).

IPLCs have been using fire to promote herbaceous vegetation and useful game or plant species (Pechony & Shindell, 2010; Valladares *et al.*, 2014). Such historical practices and other land-use legacies combined with more recent driving forces, such as land abandonment and fire suppression strategies, have been playing a major role in reshaping the Mediterranean landscapes (Blondel, 2006; Gauquelin *et al.*, 2018; Marlon *et al.*, 2008; Valladares *et al.*, 2014).

Although Mediterranean biodiversity is facing multiple threats and is declining strongly, some driving forces may be turned into conservation opportunities. For instance, large carnivores have been recolonizing abandoned landscapes in many rural areas of the Mediterranean Basin. Although land abandonment and subsequent vegetation encroachment generate conservation concerns, this process is now also considered as an opportunity for rewilding landscapes and exploring new avenues in areas where the socioeconomic context becomes incompatible with the maintenance of traditional agricultural practices (Ceaușu *et al.*, 2015; Navarro & Pereira, 2012).

2.2.7.5 Arctic and mountain tundra

Tundra vegetation, composed of low-growing herbaceous plants, shrubs, mosses, and lichens, grows beyond the cold limit of tree growth. Two types are recognized: mountain tundra at high elevations, and arctic tundra at high latitudes. Arctic tundra is found in Russia, Canada, the U.S., and Greenland but is not present in Scandinavia, Iceland, or the Aleutian Islands (CAFF, 2013; Walker *et al.*, 2005). This distribution corresponds roughly with the distribution of permafrost in soils, while mountain tundra soils have no permafrost. One effect of permafrost is that water from snow and rain is retained in the surface layers of soil; plants grow better in these moist soils than in the drier soils of mountain tundra. Species richness in the tundra is low; for example, the arctic tundra contains only 9% of the world's species of plants and animals.

The low numbers of people who live in the tundra regions have little effect on the native plants and animals. High plant productivity and low predator densities in arctic tundra (Bhatt *et al.*, 2017) support many migrating animals such as reindeer/caribou, muskox, fish, and birdlife including millions of geese. Harvest of these animals supports Indigenous Peoples and recreational hunting in temperate regions. In general, both ecosystems are still functionally intact, though in some areas used for seasonal herding, impacts are notable. Arctic and high mountain tundra are recognized as water towers (Chettri *et al.*, 2012; Viviroli *et al.*, 2007), but they are sensitive to multiple drivers including climate change (Myers-Smith *et al.*, 2015).

There are indications of higher warming in high mountains (Shrestha *et al.*, 1999) resulting in species range shifts (Gottfried *et al.*, 2012; Liang *et al.*, 2018; Pauli *et al.*, 2012; Tape *et al.*, 2016), phenology change (Bjorkman *et al.*, 2015; Tao *et al.*, 2018) and low plant productivity (Bhatt *et al.*, 2017). The arctic region is warming at roughly twice the global average (Pithan & Mauritsen, 2014), resulting in a warmer, wetter, and more variable environment. The permafrost in the high arctic has warmed by more than 0.5°C since 2007–2009 (AMAP, 2017); as a result, microbes release large amounts of carbon gases from the plant debris previously frozen in the soil (Schuur *et al.*, 2008). The carbon stored in the upper few layers of arctic soil is equal to twice the carbon in the world's atmosphere (Tarnocai *et al.*, 2009).

These transformations have profound implications for people, resources, and ecosystems (Arctic Council, 2016). IPLCs in arctic tundra report that they are already significantly challenged by changes to weather and ice conditions as well as by climate-induced shifts in hunting opportunities (e.g., fewer safe boating and hunting days, changing ice melting patterns), the animals they hunt, or the size of the grasslands they use for pastures (Cuerrier *et al.*, 2015; Huntington *et al.*, 2016; Parlee *et al.*, 2014). Mountain IPLCs perceive degrading rangeland conditions because of climate change (e.g., fewer flowers, height of the vegetation, reduced quantity of forage plants, more bare soil on pastures; Hopping *et al.*, 2016; Ingty, 2017), exacerbating alterations in mountain vegetation from high altitude pasturing for millennia (which has lowered the treeline and increased tundra in many mountain ranges; Catalan *et al.*, 2017).

2.2.7.6 Tropical and subtropical savannas and grasslands

Tropical savannas and grasslands cover about one fifth (~33 million km^2) of the global land surface (Beerling & Osborne, 2006; Ramankutty & Foley, 1999; Scholes & Walker, 1993). The ecosystem services they provide sustain the livelihoods of one fifth of the world's people, and they are also home to majority of the world's livestock and much of its charismatic wildlife (Lehmann *et al.*, 2014; Parr *et al.*, 2014; Sankaran *et al.*, 2005; Solbrig, 1996).

Savannas and grasslands are ancient ecosystems (originating 8–10 Mya) that support unique biodiversity (Bond & Parr, 2010; Murphy *et al.*, 2016; Ratnam *et al.*, 2011; Veldman *et al.*, 2015a). The misconception that they are 'derived' from forests through deforestation and other land-use processes and are therefore somewhat "degraded" has resulted in mismanagement of their biodiversity, and conversion to other land uses such as agriculture and tree plantations (Bond & Parr, 2010; Murphy *et al.*, 2016; Parr *et al.*, 2014; Ratnam *et al.*, 2016; Veldman *et al.*, 2015a). It is estimated that ~ 6.7 million km^2 of savanna, grassland and steppe habitats were converted to croplands between 1700 and 1992 (Ramankutty & Foley, 1999), with >80% of grassland and savanna habitats being converted to anthropogenic land uses by 2000 (Ellis *et al.*, 2010; Ellis & Ramankutty, 2008). Currently, the savannas of northern Australia are the least impacted savannas (Murphy *et al.*, 2016) while neotropical savannas are amongst the most threatened (Strassburg *et al.*, 2017), globally. Very little of Asia's savanna and grassland habitats remain (Lambin *et al.*, 2003; Miles *et al.*, 2006; Murphy *et al.*, 2016).

Species richness in tropical savannas and grasslands can be quite high, and in some cases comparable to forests (Murphy *et al.*, 2016), with the Neotropics and Afrotropics especially diverse (Murphy *et al.*, 2016). In forests much of the diversity resides in the tree layer, but grasses and forbs contribute substantially to plant species richness in tropical savannas and grasslands (Bond & Parr, 2010; Murphy *et al.*, 2016; Ratnam *et al.*, 2016; Sankaran, 2009).

Grazing and fire are integral features of savannas and grasslands and essential to their persistence (Bond, 2008; Bond & Parr, 2010; Parr *et al.*, 2014; Ratnam *et al.*, 2011; Sankaran *et al.*, 2004; Scholes & Archer, 1997). Semi-nomadic and transhumant grazing systems seem to better adapt to and cope with unpredictable climates that characterize these ecosystems than settled and paddocked animal husbandry. Local pastoralists use diverse indicators to understand pasture degradation and regeneration, such as adverse changes in woody or shrubby vegetation, or of unpalatable species (Admasu *et al.*, 2010; Angassa & Beyene, 2003; Jandreau & Berkes, 2016; Kimiti *et al.*, 2016; Lykke, 2000). Active fire suppression can alter species composition and lead to establishment of forest tree species at the expense of savanna trees in more mesic areas (Bond, 2008), and litter build up that fuels more intense fires when they do occur (Ratnam *et al.*, 2016; Stott *et al.*, 1990). Invasions by exotic species, both grasses and trees, may have negative impacts on the native flora and fauna, and may also alter the frequency, intensity and spatial extent of fires (Aung & Koike, 2015; D'Antonio & Vitousek, 1992; Hiremath & Sundaram, 2005; Hoffmann *et al.*, 2004; Ratnam *et al.*, 2016; Rossiter *et al.*, 2003).

Carbon schemes such as REDD+ can undermine grasslands by promoting tree planting (Abreu *et al.*, 2017; Bond, 2016; Griffith *et al.*, 2017; Lehmann, 2010; Parr *et al.*, 2014; Ratnam *et al.*, 2016; Strassburg *et al.*, 2017; Veldman *et al.*, 2015b). In this context, it becomes particularly critical to distinguish 'derived' from 'old-growth' grasslands and savannas, to avoid the significant costs of misguided afforestation of the latter.

Climate change will alter the tree-grass balance, in most continents leading to shrub encroachment and woody thickening (Bond, 2008; Bond & Midgley, 2000; Fensham *et al.*, 2005; Good & Caylor, 2011; Sankaran *et al.*, 2005). Savanna responses to different global change drivers are likely to vary both regionally, and across continents (Higgins & Scheiter, 2012; Lehmann *et al.*, 2014), due to varied vegetation-fire-climate linkages.

2.2.7.7 Temperate grasslands

Temperate grasslands comprise steppes, prairies and pampas, as well as some high-altitude veld, forest-steppes and wood-pastures, covering an area of 13 million km^2 (Dixon *et al.*, 2014; White *et al.*, 2000), or 5–10% of the global terrestrial surface. Temperate grasslands have a high biodiversity of mammals and birds, and huge stocks of carbon stored in their soil. Total carbon stocks have been estimated at 450 – 550 Gt C (18–31% of global terrestrial carbon White *et al.*, 2000) with a correspondingly high potential for carbon sequestration. The capacity to store carbon varies greatly between temperate grassland types and debate is ongoing regarding estimating this capacity (Schierhorn *et al.*, 2013; Sommer & de Pauw, 2010; Wiesmeier *et al.*, 2015.

Several global hotspots for vertebrates and vascular plants (Mittermeier *et al.*, 2004) overlap with temperate grasslands. The Eurasian steppes host the largest long-distance ungulate migrations on the planet (Tucker *et al.*, 2018). North American prairies are relatively recently formed which is why despite massive loss of area relatively few species are at risk of extinction (Risser, 1988).

No other biome has experienced the level of degradation and conversion as temperate grasslands (Henwood, 1998; Hoekstra *et al.*, 2005). In the last century ca. 60% have been converted (White *et al.*, 2000), and <10% remain in North America and Europe, with continuing decline (Gauthier & Wiken, 1988; Korotchenko & Peregrym, 2012; Molnár *et al.*, 2012). By contrast, <1% are converted in Mongolia. Important drivers of change in temperate grasslands are habitat conversion, fragmentation by transport infrastructure, and to a lesser extent local overgrazing. Most temperate grassland plants are adapted to grazing, yet excessive grazing or over haying has led to degradation in many

Eurasian grasslands (Wesche *et al.*, 2016) and in parts of South America (Piñeiro *et al.*, 2006). Invasive species are increasingly problematic, particularly in North America and South Africa (Grace *et al.*, 2001; Han & Young, 2016; Morrow *et al.*, 2015). Decreasing productivity of temperate grasslands and changes in composition towards unpalatable species are the most frequently cited trends (Bruegger *et al.*, 2014; Kakinuma *et al.*, 2014). North American grasslands continue to disappear, at rates equivalent to deforestation in the Amazon, due to conversion to cropland and excessive grazing (Ceballos *et al.*, 2010; Wright & Wimberly, 2013). Extremely rapid development threatens the integrity of Mongolia's vast steppe (Batsaikhan *et al.*, 2014).

For traditional pastoral communities, provision of livestock forage, dung as a fuel and the open landscape are the key NCP provided by temperate grasslands. Conversion to agriculture has slowed down and, in some regions reversed (e.g., Eurasian grasslands), with large-scale farm abandonment in e.g., Russia and Kazakhstan (Chen *et al.*, 2013; Jírová *et al.*, 2012). In China some restoration has commenced (Ren *et al.*, 2016). Shifts to market economies have reduced grazing pressure of livestock in several regions, including Kazakhstan and western Russia (Kühling *et al.*, 2016), and Patagonia (Coronato *et al.*, 2016). Where traditional mobile pastoral practices persist, such as in Mongolia, rangelands are still relatively intact pointing to the importance of ILK and mobility for sustainable use of highly variable rangelands (Bilegsaikhan *et al.*, 2017).

Levels of formal protection of temperate grasslands are low, at about 3.4 – 5.0% of global area (Henwood, 2012), lower than in other major terrestrial biomes. Protection is particularly low (≤ 2%) in South American pampas and the velds of Southern Africa and Australia (Peart, 2008).

2.2.7.8 Deserts and xeric shrub lands

This unit comprises large expanses of arid and hyper-arid lands in tropical and subtropical latitudes characterized by sparse often discontinuous vegetation and large expanses of bare soil. Deserts cover a total of over 33.7 million km^2, representing almost 25 per cent of the terrestrial surface of the planet (UNEP, 2006). Herbivory by large and medium-sized mammals that have evolved to these dry and sparse vegetation conditions is a distinctive feature of these habitats.

Deserts and xeric habitats are characterized by severe shortage of water and are classified as arid and hyper-arid with a precipitation to potential evapotranspiration (P/PET) ratio of 0.05 – 0.20 and < 0.05 (Sorensen, 2007). Deserts may be hot (ground temperatures up to 80°C) or cold, mainly dependent on altitude. Both deserts and xeric shrub lands can have a dense herbaceous/grassy vegetation after the rains for very short periods of the year. The desert biome holds on average an abundance of original species of 68%, highly adaptive to severe climate conditions (UNEP, 2006).

The deserts of the world occur in six biogeographical realms (UNEP, 2006), with varying degrees of anthropogenic influence: **Afrotropic deserts** south of the Sahara in Africa and in the southern fringe of the Arabian Peninsula (2.7 million km^2, mean population density of 21 p/km^2 and a relatively high human footprint; **Australasian deserts** in the Australian heartland (3.6 million km^2, less than 1 person per km^2, and the lowest human footprint); **Indo-Malay deserts**, south of the Himalayas (0.26 million km^2, mean population density of 151 p/km^2, the most intense human use); **Nearctic deserts** in North America (1.7 million km^2, high population density of 44 p/km^2 due to urbanization, and the second highest human footprint); **Neotropic deserts** in South America (1.1 million km^2, a population density of 18 p/km^2 and a lower human footprint than in North America); and **Palearctic deserts** in Eurasia north of the Himalayas and in north Africa including the Sahara (63% of all deserts, covering 16 million km^2; a density of 16 p/km^2, and the second lowest human footprint on the planet, possibly because of inaccessibility and extreme aridity. The flat Sahara and Arab deserts contrast with the mountain deserts of Central Asia.

Deserts and their fringes are currently home to some 500 million people, about 8% of the global population. Traditionally deserts support hunter-gatherers, pastoralists and farmers (in oases and along rivers). Poverty affects many people living in deserts (UNEP, 2006). However, contrary to common belief, deserts are not a final stage of desertification but are natural ecosystems, providing many life-supporting services to mankind.

The main drivers of degradation are urbanization, tourism, intensive agriculture, mining, military operations and climate change. Biodiversity decline in deserts is expected to reach 58% of original species in 2050. Desert wilderness areas are expected to decline from 59% of total desert area in 2005 to 31% in 2050 (UNEP, 2006).

2.2.7.9 Wetlands

Wetlands are permanent or temporary, freshwater, brackish or marine areas, where water either covers the soil or is at or near its surface, either year-round or seasonally. They include floodplains, bogs, swamps, marshes, estuaries, deltas, peatlands, potholes, vernal pools, fens and other types, depending on geography, soil, and plant life. Their global extent remains uncertain (Davidson *et al.*, 2018), but inland wetlands are estimated at 12.1 million km^2, or 6% of the world's land surface (Ramsar, 2018). Wetlands contain about 12% of the global carbon pool, highest in peatlands

(Ferrati *et al.*, 2005; Joosten *et al.*, 2016; Ramsar, 2018). Though valuation of NCP is often problematic, wetlands are estimated to contribute 21.5–30.0% of the value of global NCP (Kingsford *et al.*, 2016). Estuaries support millions of people worldwide (Halpern *et al.*, 2012), contributing food, freshwater and protection from erosion, natural hazards and pollution (Costanza *et al.*, 2014; McCartney *et al.*, 2015; Millenium Ecosystem Assessment, 2005; Russi *et al.*, 2013). They are also often culturally important to IPLCs, often in relation to intangible (e.g., sacred) values (Pyke *et al.*, 2018; Ramsar, 2018; Verschuuren, 2005).

Natural wetlands are declining rapidly: by 0.82–1.21% per year (Davidson *et al.*, 2018; Dixon *et al.*, 2016); by 31% between 1970 and 2008 in areas studied (Dixon *et al.*, 2016), and by 87% between 1700 and 2000 (Davidson, 2014). Historical losses were mostly inland (Davidson, 2014), whereas current declines are predominantly coastal (Dixon *et al.*, 2016). Conversely, human-altered wetlands – which make up about 12% of the global total – are increasing, especially in southern Asia and Africa, mainly through conversion of natural wetlands into paddy fields, which now cover 1.3 million km^2 (Davidson, 2014; Junk *et al.*, 2013; Ramsar, 2018). Rice paddies deliver multiple NCP, including pest control, soil fertility and fish production (McCartney *et al.*, 2015). Globally, IPLCs have many traditional wetland management systems. For example, the most biodiverse Norwegian swamp woodlands are managed by traditional grazing and hay mowing (Natlandsmyr & Hjelle, 2016).

Changes in the water inflows and abstraction, and structural modifications (e.g., drainage and conversion) all directly drive the loss of inland wetlands (Ramsar, 2018). Indirect drivers include overfishing, intensive wood harvesting (e.g., in wetland forests), peat extraction, and sand and gravel extraction for construction (Ramsar, 2018). The two largest peatlands in the world (northeastern Peru and Republic of Congo) are threatened by commercial agriculture, transport infrastructure, and oil palm and timber concessions (Pearce, 2017). In estuaries, increased fluvial sedimentation due to unsustainable land-use or climate change can significantly reduce fish and benthic diversity (Nicolas *et al.*, 2010).

Freshwater marshes support disproportionately high biodiversity for their size (Kingsford *et al.*, 2016), and several wetland types found in a mosaic with forests and mires, are important for biodiversity but poorly studied (Gupta *et al.*, 2006; Struebig & Galdikas, 2006). Wetland biodiversity is declining globally, with 25% of assessed species threatened with extinction (Ramsar, 2018); 45% of mammals and 33% of birds in the South Asian Tropical Peat Swamp Forests are Near-Threatened, Vulnerable or Endangered (Posa *et al.*, 2011). The fraction of wetland area under formal protection varies widely depending on definitions used, ranging from 11.3% to 20.4% (Reis *et al.*, 2017).

Climate change is already a major driver of wetland structural change and influences water volumes, flows, temperature, invasive species, nutrient balance and fire regimes (Erwin, 2008; Finlayson, 2018). The importance of wetlands for carbon sequestration is increasingly recognized, and their loss can trigger further carbon release; annual emissions of carbon due to peat oxidation in Indonesia are equivalent to emissions from fossil fuel burning in Canada (Pearce, 2017).

Positive actions on wetlands are expanding, particularly in the USA and Europe, where wetland restoration efforts are increasing (Reis *et al.*, 2017), including monitoring of birds (Heldbjerg *et al.*, 2015) and protection of peatlands. Numerous benefits from restoration have been documented (e.g., Erwin, 2008; Reis *et al.*, 2017); the incorporation of diverse perspectives, including indigenous and local knowledge, in wetland management is crucial for effective restoration (Russi *et al.*, 2013). However, landward migration of estuaries will depend on the availability of habitats and coastal development.

2.2.7.10 Urban/semi-urban

Urban and semi-urban areas cover approximately 88 Mha, less than 0.6% of the world's land surface (Klein Goldewijk *et al.*, 2017), on which 54% of the world's population lives (World Bank, 2017). Urban expansion now is more rapid, more extensive and fundamentally different from how urban areas grew in the past (Seto *et al.*, 2010). Europe and North America dominated urban growth from 1750–1950, but in 1950–2030, the total population of African and Asian cities is predicted to grow more than tenfold – from 309 million to 3.9 billion (Ramalho & Hobbs, 2012).

Urban areas are heterogeneous in relation to biodiversity and NCP, through a variety of natural, altered and novel habitats that support varied animal and invertebrate species. Fertile soils in urban areas enable urban residents to grow food (~15–20% of the world's food; Armar-Klemesu, 2000), and green spaces provide recreational, cultural and health NCP (Gómez-Baggethun *et al.*, 2013).

Urban areas are usually rich in non-native species, whether naturalized or maintained in gardens, and extension occurs usually into agricultural more than natural land. Vegetation in urban areas often has enhanced growth relative to matched rural settings (Zhao *et al.*, 2016). Land conversion is greatly reducing the extent of green space within many of the world's cities (Bagan & Yamagata, 2014). At low levels of urban development, local species numbers may increase due to habitat heterogeneity (McKinney, 2002). Non-native species may predominate in larger than smaller settlements (as many as 50% of species in a city centre can be non-native) and accumulate over time (Muller *et al.*, 2013). Biotic homogenization increases along rural-urban gradients with city centres featuring "global homogenizers" – weeds, pests and commensals. Disease organisms and parasites can become abundant in urban systems, through the large reservoirs of animal (e.g., rats, bats, birds, foxes – (Hassell *et al.*, 2017)) and human hosts.

Attribution of trends to drivers of varied species densities can be difficult because of legacies of previous land use, transient dynamics, and few studies consider all the relevant drivers (Ramalho & Hobbs, 2012). The main direct driver is replacement of vegetation by impervious surfaces. In the US, domestic cats (mostly feral) kill 1.3–4.0 billion birds and 6.3–22.3 billion mammals per year (Loss *et al.*, 2013). Pollution in urban areas is omnipresent, with nutrients and trace metal elements coming from residential, commercial business and industrial complexes (Khatri & Tyagi, 2015). Waste treatment within or close to urban areas is a big driver of ecosystem change and threat to freshwater and animal species.

Phenotypic evolution is accelerated in urban landscapes compared to natural or agricultural ones (Alberti *et al.*, 2017), as species adapt to novel and rapidly changing conditions. Urban ecosystems can provide insights into some aspects of climate change, cities tend to have higher temperatures because of the heat island effect, higher CO_2 levels and higher nitrogen deposition (Zhao *et al.*, 2016).

Cities and municipalities have embarked on restoration of ecosystems, such as species diversity enhancement, or conversion of sewerage treatment plants to natural systems of waste treatment, filtering and purification (Allison & Murphy, 2017). In some city-regions, tree-planting as a restoration drive is combined with social interventions to create economic opportunities and address poverty (Mugwedi *et al.*, 2017).

2.2.7.11 Cultivated areas

Cultivated systems are areas in which at least 30% of the landscape is in farmland or confined livestock production and managed for food/feed production. Globally 80% of the 1.6 billion ha of cultivated lands are rainfed; 20% occur in marginally suitable areas (FAO, 2011b). Further, 43% of cultivated lands are considered as agroforestry systems with more than 10% tree cover (Zomer *et al.*, 2016). These cultivated systems are vital for sustaining food production and meeting the food and nutritional needs of growing human populations projected to exceed 9 billion people by 2050 (FAO, 2017). The world's cultivated area has grown by 12% over the last 50 years, trebling the agricultural production (FAO, 2011b) to meet food demands.

Cultivated systems can themselves be degraded through human actions, and agriculture has the potential to have massive irreversible environmental impacts (Tilman *et al.*, 2001). The combined impact of land degradation, desertification and drought affect more than 1.5 billion people in 110 countries, 90% of whom live in low income areas (FAO, 2011b). Excessive use of fertilizers and pesticides have exacerbated land and soil degradation and erosion, although appropriate soil conservation practices that reduce erosion, such as minimum tillage, are increasingly being adopted by farmers (Derpsch *et al.*, 2010). There exist also many good examples of positive interactions between agriculture and biodiversity in agroforestry systems, species-rich meadows and other managed cultivated systems with biodiversity objectives in mind.

Land conversion of natural ecosystems to agriculture continues to be a major issue. Between 2000 and 2012 global oil palm planting area has expanded from 10 to 17 million ha (Pirker *et al.*, 2016). A new paradigm, sustainable intensification (SI), is now emerging to grow more food more intensively, based on the need for increasing productivity while increasing environmental sustainability (Biodiversity International, 2017; FAO, 2011a; Garnett *et al.*, 2013).

Globally livestock production is the largest user of agricultural land and therefore also leaves a significant imprint on the environment (FAO, 2015b). Data suggest that there are large differences between production systems and type of livestock and demonstrate the importance of grasslands as a global resource (Herrero *et al.*, 2013).

Key drivers negatively affecting cultivated areas include **climate change**: IPCC (2014) predicts that climate change will reduce agricultural production by 2% every decade while demand will increase by 14% every decade until 2050. Up to 40% of the world's land surface will develop novel climates, often with new pest and weed complexes (Lobell & Field, 2007). **Pollution**: there is evidence that the use of toxic agrochemicals and systemic pesticides, such as neonicotinoids, in cultivated systems is affecting non-agricultural lands and wild biodiversity including pollinators and other beneficial organisms (Dudley *et al.*, 2017). **Invasive alien species**: transboundary pests and diseases are resulting in total crop failure and affecting the productivity of cultivated systems. Globally, annual crop losses to plant pests are estimated to be between 20 to 40 per cent of production (FAO, 2017). These drivers will negatively impact the capacity of cultivated systems to continue to provide food and feed and to ensure the sustainability of food and nutritional security of human populations in decades to come.

2.2.7.12 Cryosphere

The Cryosphere is comprised of all locations on Earth with frozen water, including the Arctic, Antarctic, and glaciated mountain ranges within the polar regions. It stores about 70% of the world's freshwater as ice (Gleick, 1996), helps to radiate energy back out to space with its high-albedo surfaces, and is home to many extremophiles (Thomas & Dieckmann, 2002). This region contains fewer, larger, and more-complex organisms than temperate and tropical ecosystems.

The Cryosphere contains many unique ecosystems: **Ice sheets, glaciers, and ice shelves** contain all of the terrestrial, and terrestrially connected, ice on Earth. This land ice provides fresh water into adjacent ecosystems during melting events. The ice is home to extreme microbes living within thin water veins between ice grains. **Sea ice** covers portions of the Arctic and Southern Oceans, varies in extent seasonally, and provides shelter and hunting opportunities for many polar animals including polar bears, seals, penguins, and orcas. **Extreme deserts**, such as the Antarctic Dry Valleys, provide insight into the limits of life on Earth, and the types of microbial ecosystems that may be on other planets (Convey, 2006). **Sub-glacial lakes** found under ice sheets, such as Lake Vostok, Antarctica, are isolated systems where organisms have evolved independently for millions of years.

Climate change is having the greatest impacts on Arctic ecosystems, where warming has occurred at more than twice the global average during the past 50 years (Pithan & Mauritsen, 2014). Arctic land ice volume (Gardner *et al.*, 2013), supporting ice shelves of the East and West Antarctic ice sheet (Hillenbrand *et al.*, 2017; Pritchard *et al.*, 2012), snow cover duration and extent (Derksen & Brown, 2012), and sea ice thickness and extent are declining (Lindsay & Schweiger, 2015). The rapid warming is causing global sea level rise (Nerem *et al.*, 2018), poleward and upward advancement of the treeline (Harsch *et al.*, 2009), altering ranges of Arctic species including polar bears (Rode *et al.*, 2012) and caribou (Vors & Boyce, 2009), altering animal diets (Rode *et al.*, 2015), shifting predator-prey relationships due to phenological mismatches (Gilg *et al.*, 2009), changing migration patterns of many species including anadromous fish (Mundy & Evenson, 2011), and desiccating terrestrial freshwater systems (Smol & Douglas, 2007). In the Southern Hemisphere, the strongest rates of warming are occurring in the West Antarctic Peninsula causing growth rates and microbial activity to rapidly increase (Royles *et al.*, 2013). The Southern Ocean also continues to warm and freshen from increased precipitation and ice melt (Swart *et al.*, 2018).

Sea level rise and severe storms have destabilized Arctic infrastructure, disrupting the physical, social, and cultural well-being of IPLCs (Cochran *et al.*, 2013), and in some cases, forcing relocation (e.g., Alaska, (Maldonado *et al.*, 2014)). ILK has been used in conjunction with Western science to further study the impact of climate change on Polar Regions (Pearce *et al.*, 2015). Trends observed by IPLCs relate mostly to population trends such as reduced number of seals and increased population size of bears (Wong & Murphy, 2016).

There are increased economic opportunities due to the increased number of ice-free days within the Northern Sea Route (Russia) and Northwest Passage (Canada), which will increase land- and freshwater-based transportation networks in the Arctic (Khon *et al.*, 2010), bringing increased risk of ecological damage. The Arctic Council and its circumpolar indigenous participant groups work to support research and legislation aimed at resolving issues surrounding sustainable development and environmental protection, through sharing of knowledge.

2.2.7.13 Aquaculture

Aquaculture converts terrestrial, freshwater or marine areas to farming of aquatic organisms, driven by depletion and stagnation of wild fisheries and rising demand and recognition of nutritional and sustainability benefits of aquaculture (Mungkung *et al.*, 2014; Pelletier *et al.*, 2011; Troell *et al.*, 2014a; Waite *et al.*, 2014). Estimates of global area of biomes converted to aquaculture does not exist – only sporadic national statistics (Ottinger *et al.*, 2016). Freshwater fish from ponds makes up 60% of global aquaculture production, marine mussels and oysters 21%, shrimps and other crustacean from ponds 10% and marine finfish (mainly cages) 8.5% (FAO, 2018). Farmed seaweed production reached 30 million tons in 2016 (FAO, 2018). China, India and Southeast Asian countries represent 80% of global aquaculture production (FAO, 2018), followed by Bangladesh, Egypt and Norway.

Aquaculture production is projected to grow 15–37 per cent by 2030 (FAO, 2018; Kobayashi *et al.*, 2015; World Bank, 2013), led by currently dominant species and countries (FAO, 2018; Hall *et al.*, 2011). Expansion faces challenges related to environmental impacts and competition for resources, e.g., feed, freshwater and energy (Bostock *et al.*, 2010; FAO, 2018; Gephart *et al.*, 2017; Pahlow *et al.*, 2015; Troell *et al.*, 2014b). Access to space will be an issue for land and coastal farming but not for offshore ocean aquaculture (Klinger *et al.*, 2017; Oyinlola *et al.*, 2018; Troell *et al.*, 2014a).

Aquaculture is the fastest growing food sector contributing 80 million tons (53 per cent) to global food fish production (FAO, 2018). Although 600 freshwater and marine species, across multiple trophic levels and culture techniques, are farmed worldwide, about 20 species comprise 84 per cent of total aquatic animal production (FAO, 2018). The value of mariculture products reached 65 billion USD in 2013, or 43 per cent of global aquaculture (Oyinlola *et al.*, 2018).

Sustainability of culture species and systems varies widely (Gephart *et al.*, 2017; Henriksson *et al.*, 2015; Klinger & Naylor, 2012; Troell *et al.*, 2014a). Today, 70% of total animal aquaculture production relies on supplemental feed (FAO,

2018) derived from a wide variety of food quality and human inedible sources, with important repercussions on the resilience of the world's food systems (Froehlich *et al.*, 2017; Naylor *et al.*, 2009; Tacon *et al.*, 2011; Tacon & Metian, 2015; Troell *et al.*, 2014a, 2014b).

Climate change and global change, including unfavorable temperature regimes, hypoxia, sea level rise, ocean acidification, floods, diseases, parasites and harmful algal blooms and freshwater shortage (Barange *et al.*, 2018; Myers *et al.*, 2017) challenge aquaculture production. Antimicrobial use in aquaculture is also a cause of concern in relation to antimicrobial resistance (AMR) (Han *et al.*, 2017; Henriksson *et al.*, 2018; Rico *et al.*, 2012).

Aquaculture can contribute to the global sustainability goals by providing incomes and supporting food security, especially in low and medium income countries. (Béné *et al.*, 2016; FAO, 2017). Farmed fish and shellfish are high in protein and rich in micronutrients, and employment is created throughout the aquaculture value chains (Béné *et al.*, 2016; Beveridge *et al.*, 2013; Bostock *et al.*, 2010). However, corporate and community aquaculture have very different benefit sharing outcomes, particular for the poor. This requires appropriate policy development in producer countries.

2.2.7.14 Inland waters

Inland waters are permanent water bodies, including all types of lakes independent of salinity and depth, rivers, streams, ponds, water courses, cave waters). Declines in biodiversity of fresh waters are greater than those in the most affected terrestrial ecosystems (Dudgeon, 2005; Sala *et al.*, 2000). In Europe, 59% of freshwater mollusks, 40% of freshwater fishes and 23% of amphibians are threatened with extinction, due to chemical stressors, climate change and UVB radiation (IUCN, 2017). Freshwater species populations suffered an 81% decline (WWF, 2016).

Total diversity of fresh waters is far from being completely studied (Cazzolla Gatti, 2016). 115–188 new amphibian species were described annually between 2004–2016 (Amphibia Web, 2017). Since 1976 around 305 fish species have been described annually (Reid *et al.*, 2013). Lake Ohrid is a major European biodiversity hotspot, characterized by its narrow endemism, however this is under threat from a wide range of anthropogenic pressures (Kostoski *et al.*, 2010).

Flow modification is a particular risk for river ecosystems degradation. Dams change turbulent flowing waters to still, creating unfavourable conditions for specialist and endemic species and altering assemblages of taxonomic groups (Liermann *et al.*, 2012). Retention of water in dams is as high as five times the volume of all the world´s rivers (Nilsson & Berggren, 2000). 172 out of the 292 large river systems are affected by dams, with Europe having the smallest number of completely unfragmented river systems (EEA, 2015; Nilsson *et al.*, 2005). The Mekong, Congo and Amazon are the most biodiverse river basins on Earth affected by dam construction (Winemiller *et al.*, 2016).

Global environmental changes such as nitrogen deposition, climate change, shifts in precipitation and runoff patterns (Galloway *et al.*, 2004) affect inland waters, and are superimposed upon other localized threats (Dudgeon, 2005).

Biodiversity losses can affect water quality, e.g., by loss of species that remove excessive nutrients (Cardinale, 2011). Populations of different important fish species declined significantly, while introduced species transform the original fish communities (Aigo & Ladio, 2016; Gray *et al.*, 2017).

2.2.7.15 Shelf systems

Shelf systems extend from the shoreline to 200m deep, comprising 8% of the earth's surface (Kaiser *et al.*, 2011) and contribute 90% to the world's marine primary production (Longhurst *et al.*, 1995). They are influenced by adjacent terrestrial systems and watersheds; urban, aquaculture and intensively used coastal areas; and in polar regions, the cryosphere. This makes shelf ecosystems among the most vulnerable to cumulative and intensifying local to global impacts.

Shelf systems comprise several subunits: **mangrove forests** and **seagrass beds** are dominated by flowering plants adapted to saltwater. Both sequester more carbon than tropical rainforests. **Coral reefs** flourish in shallow tropical seas due to symbiosis between hard corals and intracellular dinoflagellates. Other **biogenic reef** habitats are created by e.g., tubeworms, bivalves, and sponges. The intertidal zone, comprising **rocky and sandy shores**, is controlled by physical extremes and aerial exposure in upper levels, while ecological interactions dominate at lower levels. **Macroalgal** habitats become more dominant at higher latitudes, with giant kelp reaching heights of 40 m. Submerged habitats on the shelf include rocky, cobble, sand and muddy bottoms, which determine the biological communities they support. **Deep coastal inlets and fjords** support concentrated diversity hotspots. **Polar shelves** with poorly sorted sediments especially in the Southern Ocean support unusually high biomass of heterotrophs (Gutt *et al.*, 2013). **Coastal pelagic** areas include highly productive waters where plankton are the primary and secondary producers and sustain rich fisheries yield, such as polar seas, the North Sea, Sea of Okhotsk and East China Sea.

Shallow shelf ecosystems have supported human uses for tens of thousands of years as a result of their accessibility and high productivity, for fishing, natural products, tourism and coastal development. Cumulative impacts are evident (Selig *et al.*, 2014). Global cover of mangroves (134,000 km^2) has declined 37.8% (Thomas *et al.*, 2017). Shallow coral reefs have shown long-term decline (Pandolfi *et al.*, 2003) and are losing live coral cover at a rate of 4% per decade (Section 2.2.5.2.1); severe global bleaching events are increasing in frequency and intensity because of rising temperatures (Hughes *et al.*, 2018). Conditions currently unsuitable for persistence of shallow coral reefs globally are predicted to occur within the next 10–50 years at almost all reef locations globally (Beyer *et al.*, 2018; van Hooidonk *et al.*, 2016), and >33% of coral species are listed as Threatened (Carpenter *et al.*, 2008). The reef-associated fish species Living Planet Index (LPI) declined 34 per cent between 1979 and 2010 (WWF, 2015).

Drivers of shelf ecosystem decline include fishing, eutrophication, solid and liquid waste, habitat fragmentation, underwater noise from shipping and invasive species. Indirect effects of land-use change are mediated through freshwater runoff from land and in rivers. Climate change is increasingly pervasive in shelf systems (Hoegh-Guldberg *et al.*, 2014), through increasing temperature, acidification, deoxygenation and intensifying storms. They fundamentally affect species' life histories, as well as the physical structure of the coastline and shelf.

Shelf ecosystems are of great significance to IPLCs. Many coastal cultures have detailed histories and mythologies related to them (Lee, 2014), as well as centuries and even millennia-old practices and customs demonstrating intimate adaptation (Johannes, 1981). However, the commercial overexploitation and decline of many shelf ecosystems contributes to the loss of these traditions. Both IPLCs and scientists document the decline in abundance of fish species (e.g., sawfish species in Brazil) and weight of fish (e.g., goliath grouper) (Giglio *et al.*, 2015; Reis-Filho *et al.*, 2016).

Shelf ecosystems are an increasing focus for management and protection. Marine Protected Areas and sectoral tools (e.g., in fisheries, shipping, etc.) are now being integrated into novel approaches including Integrated Coastal Zone Management (Clark, 1992) and Marine Spatial Planning (Ehler & Douvere, 2009). Direct and spatially explicit conservation and protection measures are generally local, though increasingly applied at scale as countries approach 10% targets for marine area management. Improving the effectiveness of management is recognized to be equally important as area, to assure benefits accrue to users (Cinner *et al.*, 2016; Edgar *et al.*, 2014).

2.2.7.16 Surface open ocean

The surface open ocean is the shallower light-flooded layer offshore of the 200-m depth contour **(Figure 2.2.26)**. It covers 65% of the earth's surface (Kaiser *et al.*, 2011), converts regionally high amounts of carbon and nutrients to biomass, and remineralizes more than 95% of this organic matter (Ducklow *et al.*, 2001). The surface open ocean and shelf ecosystems produce 50% of atmospheric oxygen (Field *et al.*, 1998) and sequester anthropogenic CO_2, which is essentially important for almost all life on Earth. This function is expected to weaken with increasing climate change. Biological processes in the surface open ocean are driven by sunlight, nutrient availability, and water mass stratification. The unit exchanges with the deep sea through downward flux of organic matter, upwelling of nutrients and vertical migration of organisms.

The surface open ocean comprises different ecosystems: **Central Oceanic Gyres** contribute to the global dispersal of heat, nutrients and organisms. They include oligotrophic 'deserts' and highly productive areas (Westberry *et al.*, 2008). **High-Nutrient Low-Chlorophyll Systems** occur in the Southern Ocean, the subarctic and equatorial Pacific Ocean, where phytoplankton growth is not limited by macronutrients (Pitchford & Brindley, 1999). **Cold and Ice-Covered Polar Seas** are driven by high seasonality and low temperatures. Their productivity supports krill (Atkinson *et al.*, 2008), which feeds penguins, seals, and whales that migrate across the oceans. **Upwelling Systems** allow high fishing yields based on high primary production (Kämpf & Chapman, 2016). **Oxygen Minimum Zones** are caused by excess carbon decomposed by bacteria with anoxic metabolism (Karstensen *et al.*, 2008; Levin, 2003).

Due to its size, the surface open ocean is still poorly characterized in spite of centuries of ocean voyages and expeditions. Its approximately 7000 species are less than in some coastal systems and the deep sea (Bucklin *et al.*, 2010). Hotspots in species richness are for example in the marginal seas of Southeast Asia and polar regions.

The surface open ocean is vulnerable to threats, including from fisheries, pollution including waste, shipping, and noise. Environmental changes have been documented in ocean circulation and chemistry, thermal stratification, composition and growth of phytoplankton (Boyce & Worm, 2015; Sarmiento *et al.*, 2004), biogeochemical cycling (Hoegh-Guldberg & Bruno, 2010; O'Brien *et al.*, 2017), and distribution of ecologically key species (e.g., Beaugrand, 2009) with effects on food webs (Knapp *et al.*, 2017; Smith *et al.*, 2008). Fishing has altered trophic relationships (Pauly *et al.*, 1998; Richardson *et al.*, 2009), the number of overexploited fish stocks, e.g., of tuna and billfish has increased over the past decades resulting in regionally declined fishing yields by 50% (Sherman & Hempel, 2009;

Worm *et al.*, 2005). Waste accumulation is documented though poorly known (Bergmann *et al.*, 2015). Extinction risk for open ocean species has been assessed for seabirds, tuna and sharks (Brooks *et al.*, 2016).

The ocean surface is sensitive to climate change**,** experiencing a globally averaged 0.44°C warming between 1971 and 2010 (IPCC, 2014). Ocean acidification affects not only key calcifying pelagic organisms, such as pteropods and coccolithophorids, it potentially changes the physiology of all species (e.g., Manno *et al.*, 2007).

Interactions of IPLCs with the surface open ocean includes the historic navigation of Micronesian and Polynesian seafarers (Lee, 2014) and is found in notes of captains of fishing vessels, whalers, and explorers (Holm *et al.*, 2010; Rodrigues *et al.*, 2016).

Protective management of surface open ocean systems is increasing as they become less remote with modern technology, trade and extension of governance regimes. In spite of increased pressure, the number of sustainably managed fish stocks has increased (FAO, 2014b; Marine Stewardship Council, 2016). Targeted species such as Antarctic fur seals and humpback whales are recovering (Zerbini *et al.*, 2010) and strategies to reduce by-catch by longlines and driftnets of e.g., turtles, albatrosses, and dolphins are being developed (Hall *et al.*, 2000; Kennelly, 2007). The area of ocean under protection is expanding with accelerating designation of Marine Protected Areas and development of legally binding instruments for governing the High Seas (Wright *et al.*, 2015a).

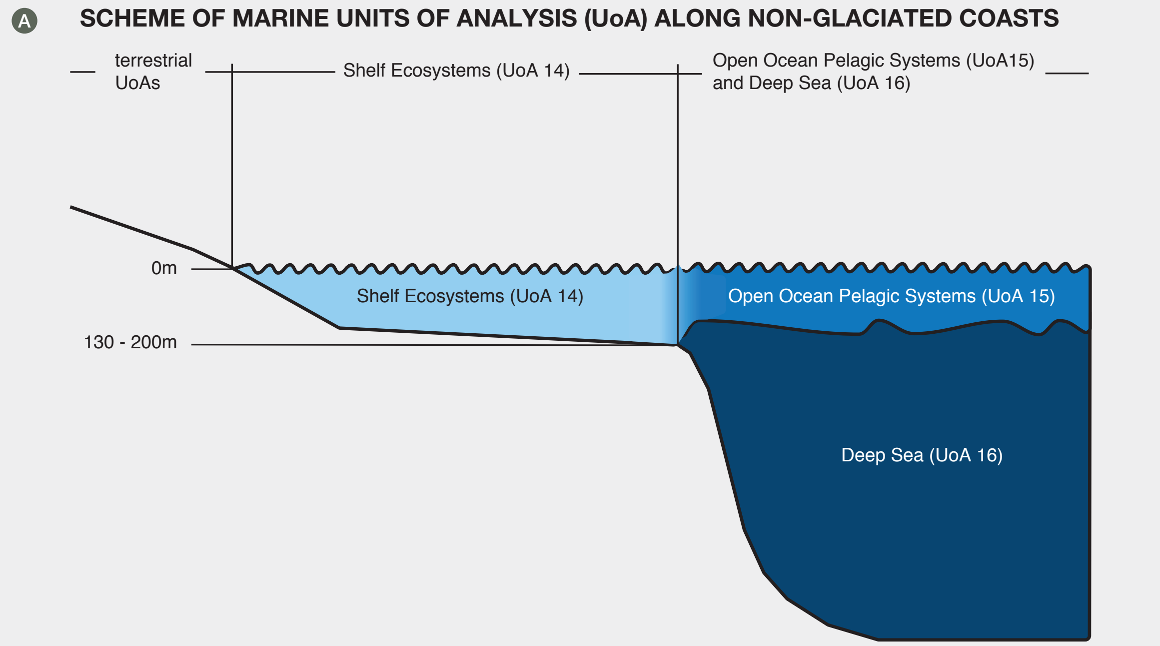
2.2.7.17 Deep sea

The deep sea is the largest and most three-dimensional habitat on Earth. It comprises the dark waters below the euphotic zone (200 m, **Figure 2.2.25**), where biological processes remineralise nutrients and sequester carbon, including of anthropogenic origin, as well as other ecologically important elements. Almost all life in the deep sea depends on climate-sensitive biological processes in the surface layer (Smith *et al.*, 2008) and in the sea ice (unit 11). Through the globally connected current system damage to deep sea ecosystems, especially by pollution, affects natural resources directly used by man.

The deep sea comprises a number of components: the **Slope and Rise of Continents and Islands** from 200 to 4000 m depth, are characterized by characterizedverse environmental gradients and peak benthic species richness between 1500 and 3000 m (Ramirez-Llodra *et al.*, 2010). The **Abyssal Plain** from 4000 to 6000 m covers the largest area (more than 50% of the Earth's surface), where due to limited food availability metabolic rates and biomass are low (Woolley *et al.*, 2016). Faunistic depth gradients are superimposed by a decrease in species richness from the equator to the poles (Ormond *et al.*, 1997). One of the most speciose bottom-dwelling animal groups are nematodes (e.g., Danovaro *et al.*, 2010), whilst bacteria perform highest biological turnover rates. The **Mid-Ocean Ridges** are created by seafloor spreading, with peaks between 5000 and 2500 m above the abyssal plains. Their complex topography and variable sediments shape seabed and pelagic assemblages (Vecchione *et al.*, 2010). **Vents and Seeps** provide energy in the form of methane and sulphides, driving chemosynthetic food webs based on specialized microorganisms (Baker *et al.*, 2010); similar communities develop on whale falls. Some vents provide clues to the deep biosphere living within deep sediments and the ocean crust (Schippers, 2016). **Seamounts** rise more than 1000 m above the surrounding seabed (Clark *et al.*, 2009), where upwelling of nutrients increases biological productivity. Their sessile benthic filter feeding biota is highly endemic (Richer de Forges *et al.*, 2000). Seamount productivity supports abundant fishes, sharks, turtles, marine mammals and seabirds. **Deep-Water Coral Reefs** create a three-dimensional habitat for a rich associated fauna without light-enhanced growth (Freiwald *et al.*, 2004). **Deep-Sea Trenches** occur between 6000 and 11,000 m depth, with a fauna low in abundance and biomass. Life in the **Deep Aphotic Pelagic Zones**, including the meso-pelagic twilight zone (200–1000m; Sutton *et al.*, 2017), and the bathyal, abyssal, and hadal zones (1000–11,000 m) mostly depends on organic matter falling from the light-flooded surface water layers. It comprises gelatinous invertebrates and midwater fish adapted to a stable environment (Ramirez-Llodra *et al.*, 2010).

The low abundance of organisms and low scientific sampling in the deep sea and an assumed high proportion of range-restricted species make species numbers hard to assess, but it is thought rival other global biodiversity hotspots (Knowlton *et al.*, 2010).

Anthropogenic damage in the deep sea is less than in shallow waters and on land but is increasing rapidly. A severe impact is bottom trawling (Clark *et al.*, 2015) on fish (e.g., grenadiers and orange roughy), resulting in rapid decline of yields of slow growing species after a short phase of overfishing and damage to unique benthic habitats, especially on seamounts. Deep-sea mining is expected to be a major threat in the near future (Jones *et al.*, 2017). Long-term effects of dumped waste, especially radioactive material and plastics is still largely unknown (Bergmann *et al.*, 2015). Due to adaptation to a stable environment most deep sea organisms are sensitive to environmental changes, especially to climate-induced shifts in energy supply, alteration of biogeochemical cycles including ocean acidification and prey-predator interactions.



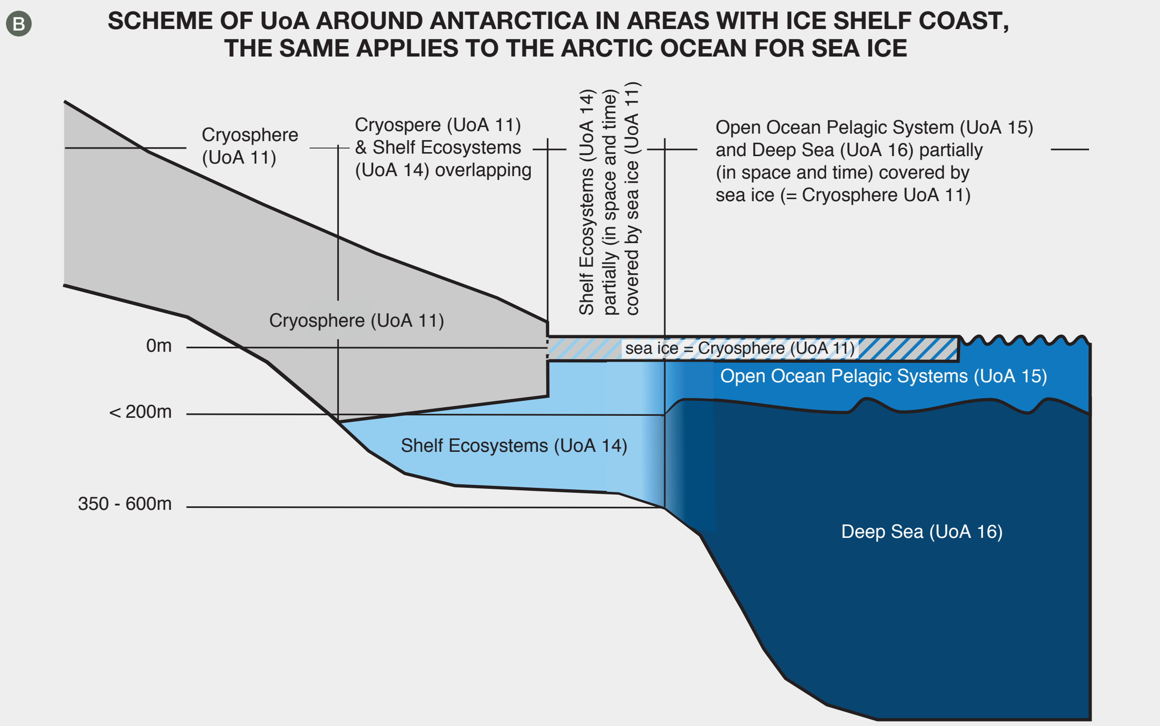


Figure 2 2 25 **A The ocean units (14, 15 and 16) are distinguished across biological and environmental gradients rather than by discrete differences in water masses, nutrient supply, sediment characteristics, and species assemblages. The boundary between units 15 and 16 is usually denoted by the compensation depth, above which primary production happens, and set by convention at approximately 200 m depth, but this can vary over space. B the relationship between shelf (unit 14) and open ocean (unit 15) units and the crysophere (unit 11) is complex, as ice layers over water and may be land-fast or free-floating. Further, the boundary between units 14 and 15/16 is at the 200-m depth contour around most continental shelves, down to 500 m in Antarctica.**

Historic indigenous knowledge on deep sea organisms is common to many ancient seafaring cultures, in the form of tales of mythical bizarre creatures from an unknown world (Ellis, 2006). Conservation of deep sea habitats is still rudimentary and sectoral, but concepts for ecosystem management and Marine Protected Areas to reduce the impact of bottom trawling (Wright *et al.*, 2015b) and deep sea mining (Wedding *et al.*, 2013) exist.

2.2.7.18 Coastal areas intensively and multiply used by humans

The coastal area includes the coastal waters, the seabed, adjacent land and nested waterbodies (including freshwater). Coastal areas extend along more than 1.6 million km of coastline in a total of 123 countries (UNEP, 2006). At present a third of the world's population is living in the coastal zone and almost 40% of the world lives within 100 km of the coast (Agardy *et al.*, 2005).

Coastal areas are experiencing an intensification of multiple uses, due to human population growth, migration from inland regions, tourism and economic growth. Coastal land is used for human settlement, agriculture, trade, industry and amenities. The coastal sea is intensively used for transport, fishing, dumping, mining, and more. Furthermore, coastal areas are the "sink" for the continents; they receive and concentrate pollutants and other negative consequences of anthropogenic activities. Carbon cycling in the coastal sea that connects terrestrial with open ocean systems plays an important role in the global carbon cycles and budgets (Regnier *et al.*, 2013). Tourism is a very important driver in many regions and is responsible for a great increase of pressure in coastal areas. Continued human uses and pressures in coastal zones will have an important impact on the future evolution of the coastal ocean's carbon budget.

Coastal areas intensively and multiply used by humans is an anthrome, defined by artificial constructions linked to human settlements, industry, aquaculture, or infrastructure that transforms coastal habitats (Lazarus, 2017). These include a) coastal defences (breakwaters, groynes, and jetties), b) coastal protection (seawalls, bulkheads, and pilings), c) floating docks, e) artificial islands, f) dumping and mining areas, g) artificial structures for energy (including renewable energies) and h) port development and coastal support. Population growth, industrial and tourist development, pollution, habitat and biodiversity loss, changes in access rights, markets and technology and increasing drivers of global change are threatening the future sustainability of coastal areas. Although many of these changes occur in other ecosystems, they are particularly concentrated on the coast.

People living in the coastal areas and particularly poor coastal communities, have adapted to transformations in coastal ecosystems. But now they face an environment of increased competition from high-density and industrial uses, in which access to the resources they depend on is becoming more and more restricted. Additionally, future sea-level rise is also putting pressure on coastal areas. Coastal management needs to encompass decisions of which uses to regulate, which uses to promote, and which NCP are most important to citizens and businesses (Loomis *et al.*, 2014) to provide for sustainable use of the resources of the coastal areas, by addressing trade-offs between conflicting multiple uses.

There is an urgent need for a holistic coastal zone management approach (integrated, multiple use oriented) to provide mediation through administrative procedures, public hearings and facilitated dialogue, for stakeholders (including coastal communities and local and central governments) to be represented in negotiations. Strengthening the integration of IPLCs and ILK in multiple use planning and management in the coastal areas is essential to long-term sustainability of coastal areas (Lockie *et al.*, 2003).

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Chapter **2.3**

STATUS AND TRENDS – NATURE'S CONTRIBUTIONS TO PEOPLE (NCP)

IPBES GLOBAL ASSESSMENT REPORT ON BIODIVERSITY AND ECOSYSTEM SERVICES
CHAPTER 2.3. STATUS AND TRENDS - NATURE'S CONTRIBUTIONS TO PEOPLE (NCP)

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CHAPTER **2.3**

STATUS AND TRENDS – NATURE'S CONTRIBUTIONS TO PEOPLE (NCP)

EXECUTIVE SUMMARY

1 **Nature underpins quality of life by providing basic life support for humanity (regulating), as well as material goods (material) and spiritual inspiration (non-material) (*well established*) {2.3.1, 2.3.5}.** We classify nature's contributions to people (NCP) in 18 categories: (a) regulating environmental processes that affect filtering pollutants to provide clean air and potable water, sequestering carbon important for climate change, regulating ocean acidification, protecting soil quality, providing pollination and pest control, and reduction of hazards. For example, marine and terrestrial ecosystems are the sole sinks for anthropogenic carbon emissions, with a gross sequestration of 5.6 gigatons of carbon per year (the equivalent of some 60 per cent of global anthropogenic emissions), (b) nature plays a critical role in providing food and feed, energy, water, medicines and genetic resources and a variety of materials fundamental for people's physical well-being and for maintaining culture. For example, the combined market value of livestock and fisheries was nearly $1.3 trillion in 2016; more than 2 billion people rely on wood fuel to meet their primary energy needs; between 25–50% of pharmaceutical products are derived from genetic resources; and some 70 per cent of drugs used for cancer are natural or are synthetic products inspired by nature; (c) non-material contributions, such as inspiration and learning, physical and psychological experiences, and supporting cultural identities (Section 2.3.1). Tourism to protected areas, for example, generates an estimated $600 billion annually. Regulating, material, and non-material contributions of nature are not independent; they are linked through both positive and negative interactions. These contributions occur in the present and will also be important as conditions change into the future. Therefore, nature is essential in (d) maintaining humanity's ability to choose alternatives in the face of an uncertain future.

2 **Creation of knowledge from different sources, whether indigenous and local knowledge (ILK) or from scientific organizations, have made significant contributions to NCP and good quality of life (*well established*) {2.3.1, 2.3.2, 2.3.3, and 2.3.4}.** ILK has enhanced NCP through identification of natural medicinal resources, agriculture, and materials, and by providing a diversity of conceptualizations of nature linked to non-material NCP. ILK has contributed to learning and identity, as well as patterns of ecologically-friendly management systems within biodiversity-rich landscape mosaics that favor diversity of habitats and pollinators, fertile soils, and maintenance of future options. The scientific approaches used to assess and measure NCP have increased understanding of ecosystems, biodiversity, and their contribution to good quality of life. Scientific approaches can be grouped into six major classes, based on the particular features of each NCP: evaluation of (a) biophysical processes; (b) ecological interactions; (c) habitats and land cover types; (d) direct material use of organisms; (e) human experiences and learning; and (f) diversity of life on Earth. Greater integration of multiple knowledge systems shows promise for improving use and scaling of NCP impacts. In this chapter, we performed a systematic review of more than 2000 studies of NCP trends during the past 50 years, considering knowledge from ILK as well as scientific organizations.

3 **Most NCP are co-produced by biophysical processes and ecological interactions with anthropogenic assets such as knowledge, infrastructure, financial capital, technology and the institutions that mediate them. However, some NCP, such as the maintenance of options from the pool of genetic diversity available on earth, are produced with little to no human contribution (*well established*) {2.3.1, 2.3.2}.** For example, marine and freshwater-based food is co-produced by the combination of fish populations, fishing gear, and access to fishing grounds {2.3.3}. Co-production of nature's contributions changes in response to human drivers {2.3.2}. For example, conversion of vegetated land to paved surfaces or bare soil reduces the potential for natural water filtration, while management to improve the functional composition of filtering vegetation or building artificial treatment wetlands increases it. The degree to which anthropogenic assets are used in the co-production of NCP varies among and within NCP and may vary across space and time.

4 There is an important distinction between potential NCP, realized NCP, and output of co-production (*established but incomplete*) {2.3.1, 2.3.2}. Potential NCP is the capacity of ecosystems to provide NCP, while realized NCP is the actual flow of NCP that humanity receives. For example, the extent to which vegetation filters pollution to regulate water quality (a **realized NCP**) depends on pollution type and levels, rates of water flow, and the filtration capacity of nature (**potential NCP**). Water quality (the **output of co-production**) depends on the relative rates of pollution and filtration as well as whether pollution feeds back to degrade vegetation and soil filtration capacity. The installation of a water filtration facility will increase the output of co-production and modify the impact on good quality of life. The distinction between potential and realized NCP highlights the importance of maintaining current biodiversity for future options.

5 Since 1970, trends in agricultural production, fish harvest, bioenergy production and harvest of materials have increased – which are 3 material contributions from nature that result in production of marketed commodities, but 14 of the 18 categories of contributions of nature that were assessed, mostly regulating and non-material contributions, have declined. The regulation of ocean acidification showed no consistent global change (*established but incomplete*) {2.3.5}. For example, materials such as production of industrial timber has increased to 608 million m^3 in 2017 (+48% relative to 1970 levels), while its import value has increased more than sixfold (US $2.6 billion in 1970 to US $16.6 billion in 2017). Similarly, the value of agricultural crop production ($2.6 trillion in 2016) has increased approximately threefold since 1970 and raw timber harvest has increased by 45 per cent, reaching some 4 billion cubic meters in 2017, with the forestry industry providing about 13.2 million jobs. In contrast, emission of air pollutants (e.g., $PM_{2.5}$), has increased in many parts of the globe affecting air quality. Only about a tenth of the global population is estimated to breathe clean air, leading to an estimated 3.3 million premature deaths annually, predominantly in Asia. Indicators of regulating contributions, such as soil organic carbon and pollinator diversity, have declined, indicating that gains in material contributions are often not sustainable. Currently, land degradation has reduced productivity in 23 per cent of the global terrestrial area, and between $235 billion and $577 billion[1] in annual global crop output is at risk as a result of pollinator loss. Moreover, loss of coastal habitats and coral reefs reduces coastal protection, which increases the risk from floods and hurricanes to life and property for the 100 million–300 million people living within coastal 100-year flood zones.

1. Value adjusted to 2015 United States dollars taking into account inflation only.

6 The trend in the output of co-production of many NCP differs from the trend in potential NCP and realized NCP. In general, trends for potential NCP are more negative than those for output. Potential NCP has declined since the 1970s for 14 of the 18 NCP, while others show contrasting trends among proxies of the same NCP (*established but incomplete*) {2.3.1, 2.3.5}. For example, agricultural production (output of co-production) has been increasing worldwide, attributed in part to greater agrochemical consumption, but the capacity of nature to support food production (potential NCP), including pollination, pest control, genetic diversity for crop breeding, and the production of wild food has decreased. Furthermore, all taxa of wild crop relatives have decreased, with an estimated 16–22% of species predicted to go extinct and most species losing over 50% of their range size. Another example, as anthropogenic air or water pollution increases, nature provides more filtration (realized NCP increase), but filtration capacity is limited leading to declines in air and water quality (output of co-production).

7 Declines in potential NCP affect both current and future output of co-production and realized NCP (*established but incomplete*) {2.3.2}. The world has lost approximately 8% of total global soil carbon stocks, reducing productivity in 23% of global terrestrial area. Similarly, lost species affect many NCP; for example, global loss of wild pollinators affects a wide range of plants, including major crops. In addition, around 20% of known medicinal species are currently threatened, affecting the large portion of the global population who rely on natural medicines as well as affecting the potential to identify new medicinal compounds. Some declines in NCP can be recovered with ecosystem restoration while other declines are irreversible.

8 Some increases in material NCP are not sustainable (*well established*) {2.3.5}. Harvests exceeding resource replacement rates reduce stocks essential for future supply in many places of the world. This includes overfishing, land expansion for conventional agricultural production, and overharvesting of natural medicinal plants and wood. In the case of marine fisheries, it is estimated that catch has been reduced by up to 36% of its potential in certain areas due to unsustainable fishing practices. This is a trade-off between present and future availability.

9 There are important interactions among NCP, including trade-offs and synergies (*established but incomplete*) {2.3.5}. For example, clearing of forest for agriculture has increased the provision of food and feed (NCP 12) and other materials important for people (such as natural fibers, and ornamental flowers: NCP 13) but has reduced contributions as diverse as pollination (NCP 2), climate regulation (NCP 4), water quality regulation (NCP 7), opportunities for learning and inspiration (NCP 15), and the maintenance of options for the future (NCP 18). However, very few large-scale systematic studies exist on those relationships. Indeed, the decline in pollinator diversity is challenging the production of more than 75 per cent of global food crop types, including fruits and vegetables and some of the most important cash crops such as coffee, cocoa and almonds, rely on animal pollination {2.3.5.2}. Moreover, nearly 90 per cent of wild flowering plant species depend, at least in part, on the transfer of pollen by animals. These wild plants critically contribute to most NCP. On the other hand, natural or semi-natural habitat restoration (NCP 1) can benefit many NCP simultaneously, such as pollination (NCP 2), regulation of air quality (NCP 3), regulation of climate (NCP 4), regulation of freshwater quality (NCP 7), regulation of soil (NCP 8), natural hazard regulation (NCP 9), pest control (NCP 10), learning (NCP 15), and maintenance of options (NCP 18). Globally, there are important initiatives to reduce negative impacts associated with production of material NCP. Synergies also exist, such as those associated with sustainable agricultural practices (e.g., integrated pest management, conservation agriculture, integrated and multi-purposes agroforestry systems, irrigation management, among others) enhance soil quality, thereby improving productivity and other ecosystem functions and services such as carbon sequestration and water quality regulation – many of these synergistic opportunities, which can enhance regulating, material, and non-material NCP, are being implemented already in 9% of worldwide agricultural land. The improvement of pollinator diversity through sustainable intensification could increase crop yields by a median of 24% {2.3.5.2}.

10 **There are large differences in trends in NCP in different parts of the world (*well established*) {2.3.5}.** NCP trend differently across the globe because of differences in direct drivers (chapter 2.1), specifically deforestation and other land conversion, pollution, harvesting, invasive alien species, and climate change {2.3.5}. Because tropical and subtropical regions are undergoing the most pronounced land conversions, primarily for agriculture, potential NCP has declined most in these regions over the past 50 years. For example, deforestation in the tropics offsets the ability of tropical forests to regulate climate (NCP 4).

11 **For a NCP to positively impact quality of life it must be available, accessible, and valued (*well established*) {2.3.2}.** Accessibility and value depend on individual and cultural preferences, institutions, policies, power relations, location, knowledge, experience, demographic variables, and income. The impact on good quality of life depends on the location of people relative to the co-production of different NCP. Cultures may also view nature as contributing to different categories of NCP. For example, the harvest of animal or plant species may contribute to material standard of living by providing nutritious food or providing raw materials for clothing or shelter, while particular animals and plants play a central role in cultural identity or spiritual practices in certain cultures but not others {2.3.2.4}.

12 **Many NCP that are co-produced in one place impact quality of life in regions far away (*well established*) {2.3.5}.** For some regulating NCP, this is because their impacts are inherently global, such as climate regulation. The maintenance of future options is also a global benefit, such as in the case of drug discovery. For many NCP, however, distant impacts occur because goods are moved across the globe. Flows of resources both direct (e.g., commodities) and indirect (e.g., virtual water) can shift the burden and benefit of NCP co-production to distant communities.

13 **Many of nature's contributions to people are essential for human health (*well established*) and their decline thus threatens a good quality of life (*established but incomplete*) {Section 2.3.4}.** For example, there are at least four means by which NCP impact human health: (a) dietary health-nature provides a broad diversity of nutritious foods, medicines, and clean water, including the fact that 840 million individuals lack access to enough calories, but an even larger number, 2.1 billion, fail to access sufficient food of a quality for good health of which biological diversity is a key component; (b) environmental exposure (e.g., reduce levels of certain air pollutants), which includes the health risk associated with degradation of environmental quality, such as air and water pollution flagged as fifth and ninth in terms of global risk by the Global Burden of Diseases study, respectively; (c) can help to regulate disease and the immune system (i.e., exposure to communicable diseases), for example, reducing ecological complexity and diversity concentrates disease vectors and risk, whereas diversified communities dilute risks; and (d) psychological health through improve mental and physical health through exposure to natural areas, for example, visitation rates to national parks, or urban green spaces all suggest strong happiness or psychological well-being values associated with nature.

14 **Impacts of declining NCP vary among people and geographies. Although important examples exist, a systematic assessment of impacts across social groups is not possible because studies are scarce (*well established*) {2.3.5}.** NCP with variable impact include: (a) coastal protection: the loss of mangroves exposes coastal communities to storm damage more so than people who live inland; (b) food and medicine are more available to people in areas with little direct access, such as urban areas, and to those with market access, such as those with higher income; (c) psychological experiences: urbanization can increase isolation of people from nature by

decreasing direct access and thus decrease the mental health benefits of nature; (d) pollinator loss will likely have a larger impact on human health in areas with micronutrient deficiencies, such as Southeast Asia, where 50% of the production of plant-derived sources of vitamin A requires biotic pollination {2.3.5.2}; (e) despite increasing food production, leading to production levels high enough to satisfy the caloric needs of all people on earth, around 11% of the world population is undernourished and at the same time 39% suffer from obesity; and (f) changes in pollination (NCP 2), pest regulation (NCP 10), and soils (NCP 8) are likely of greater importance for commercial farmers, while regulation of freshwater quality (NCP 7) and regulation of ocean acidification (NCP 5) are likely of greater importance for commercial fishers {2.3.5.3}. In addition, contributions that benefit some people may do so at a cost to others, such as when food production reduces downstream water quality.

15 **Most of nature's contributions to people are not fully replaceable, and some are irreplaceable (*established but incomplete*) {2.3.2}.** Loss of diversity, such as phylogenetic and functional diversity, can permanently reduce future options, such as the domestication of wild species that might be domesticated as new crops and/or-be used for genetic improvements of existing ones {2.3.5}. People have created substitutes for some other contributions of nature, but many of them are imperfect or financially prohibitive {2.3.2.2}. For example, high-quality drinking water can be realized either through ecosystems that filter pollutants or through human-engineered water treatment facilities {2.3.5.3}. Similarly, coastal flooding from storm surges can be reduced either by coastal mangroves or by dikes and sea walls {2.3.5.3}. In both cases, however, built infrastructure can be extremely expensive, incur high future costs and fail to provide synergistic benefits such as nursery habitats for edible-fish or recreational opportunities {2.3.5.2}. Substitutes for natural medicines are often financially prohibitive: an estimated 4 billion people rely primarily on natural medicines for their healthcare, mostly in lower income countries. Accounting for the wide range of benefits provided by many of NCP decreases the extent to which human-made alternatives make good substitutes. For example, hand pollination might partly replace the pollination role of wild animals for some crops, but it cannot replace pollination of wild plants nor the cultural value of pollinator species. More generally, human-made replacements often do not provide the full range of benefits provided by nature {2.3.2.2}.

16 **Studies linking co-production and impact on quality of life are scarce. For some NCP, there is a gap between what is commonly measured for the output of co-production and what is most important for impact on good quality of life. Assessing the impact on good quality of life requires synthesis and integration across all NCP (*well established*) {2.3.3, 2.3.5}.** Environmental sciences to date have focused on people's impacts on nature and ecosystem processes. More data is available to characterize either co-production or good quality of life, but there are few studies on the links between the two. For example, in large regions of the world, conventional agriculture is oriented to crop production that does not contribute directly to food security and nutrition (e.g., oil palm, soybean, maize or sugar cane for biofuels or industrial uses). Furthermore, while current food production largely meets global caloric needs, it fails to provide the dietary diversity, notably in fruits, nuts, and vegetables, required in a low health risk diet. Non-biophysical measures and multiples values held by different users groups need to be considered in assessment of good quality of life. Integrated evaluation of good quality of life will highlight the importance of enhancing multiple NCP in the long-term.

2.3.1 INTRODUCTION

This section reviews evidence about the current status and trends of nature's contribution to people (NCP) and highlights how changes in nature can have a profound impact on people's quality of life. NCP is defined to include both positive and negative contributions to good quality of life for which nature is a vital, but not necessarily the sole, contributing factor.

Nature contributes to good quality of life in many ways, from providing the basic life support system for humanity to providing material goods and spiritual inspiration. This section describes 18 categories of NCP that cover a wide range of direct and indirect contributions to humanity (see **Table 2.3.1**) (Díaz *et al.*, 2018). These contributions include the regulation of environmental conditions such as regulation of climate, air, water, and oceans; the provision of material goods such as energy, food, medicines, and raw materials; and non-material contributions such as opportunities for learning, inspiration, and spiritual, cultural, and recreational experiences that underpin quality of life. Each NCP can contribute to quality of life in multiple ways. For example, the provision of food can contribute both to material standard of living as well as to cultural practices and social relationships. The 18 categories of NCP included here capture widely agreed contributions of nature to quality of life. Though the 18 NCP cover a wide array of values and concepts, they do not include all potential values of nature, such as the value of nature for its own sake.

In focusing on NCP to connect nature and good quality of life, this section distinguishes between several closely related concepts **(Figure 2.3.1)**. There is a critical distinction between "potential NCP" and "realized NCP" (Hein *et al.*, 2016; Jones *et al.*, 2016; Villamagna *et al.*, 2013). Potential NCP is the capacity of an ecosystem to provide NCP. For example, a productive marine ecosystem may support abundant fish populations, which could in turn support a vibrant fishery that provides food for human consumption. But without anthropogenic inputs such as boats and fishing gear, and time and effort invested in harvesting efforts, the NCP related to harvesting fish will not be realized. Similarly, a terrestrial system with rich soil and favourable climate could support a high-yielding agricultural crop production system, but without farm equipment and labour, crops will not be harvested. Realized NCP is the actual flow of NCP that humanity receives. Realized NCP typically depends not only on potential NCP but also on anthropogenic assets

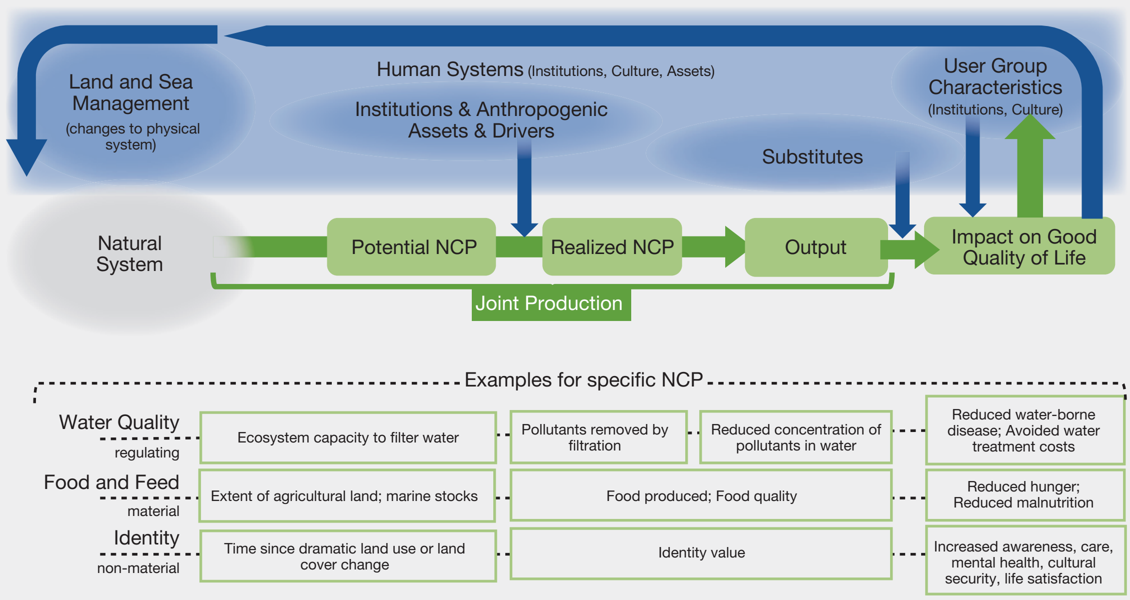

Figure 2 3 1 **Differentiation of Potential NCP, Realized NCP, Output, and Impact on Good Quality of Life.**

The figure illustrates the relationship between potential NCP, realized NCP, output, and impact on good quality of life. Ecosystems, as altered by human management, lead to co-production of potential NCP. The combination of potential NCP along with human inputs leads to realized NCP. For some NCP, there is a difference between realized NCP and output, either because of differences between what the NCP measures and what people care about, or because of substitutes. Outputs as modulated by substitutes, institutions, and culture, impact good quality life. Information about how NCP impact on good quality of life can be used to modify human management and inputs, shown by the arrow from impact on good quality of life to the blue region that represents human systems and back to the green region often via natural systems and joint production.

Table 2 3 1 **List and definition of 18 NCP included in the IPBES conceptual framework, adapted from Díaz *et al.* (2018). See also chapter 1, Figure 1.3.**

	NCP Name	Brief explanation (full definition and evidence provided by NCP in Supplementary Materials - Appendix 2)
1	Habitat creation and maintenance	The formation and continued production, by ecosystems, of ecological conditions necessary or favourable for living beings important to humans
2	Pollination and dispersal of seeds	Facilitation by animals of movement of pollen among flowers, and dispersal of seeds, larvae, or spores of organisms beneficial or harmful to humans
3	Regulation of air quality	Regulation (by impediment or facilitation) by ecosystems of atmospheric gases; filtration, fixation, degradation, or storage of pollutants
4	Regulation of climate	Climate regulation by ecosystems (including regulation of global warming) through effects on emissions of greenhouse gases, biophysical feedbacks, biogenic volatile organic compounds, and aerosols
5	Regulation of ocean acidification	Regulation, by photosynthetic organisms, of atmospheric CO_2 concentrations and so seawater pH
6	Regulation of freshwater quantity, location and timing	Regulation, by ecosystems, of the quantity, location and timing of the flow of surface and groundwater
7	Regulation of freshwater and coastal water quality	Regulation, through filtration of particles, pathogens, excess nutrients, and other chemicals, by ecosystems of water quality
8	Formation, protection and decontamination of soils	Formation and long-term maintenance of soils including sediment retention and erosion prevention, maintenance of soil fertility, and degradation or storage of pollutants
9	Regulation of hazards and extreme events	Amelioration, by ecosystems, of the impacts of hazards; reduction of hazards; change in hazard frequency
10	Regulation of organisms detrimental to humans	Regulation, by ecosystems or organisms, of pests, pathogens, predators, competitors, parasites, and potentially harmful organisms
11	Energy	Production of biomass-based fuels, such as biofuel crops, animal waste, fuelwood, and agricultural residue
12	Food and feed	Production of food from wild, managed, or domesticated organisms on land and in the ocean; production of feed
13	Materials and assistance	Production of materials derived from organisms in cultivated or wild ecosystems and direct use of living organisms for decoration, company, transport, and labour
14	Medicinal, biochemical and genetic resources	Production of materials derived from organisms for medicinal purposes; production of genes and genetic information
15	Learning and inspiration	Opportunities for developing capabilities to prosper through education, knowledge acquisition, and inspiration for art and technological design (e.g., biomimicry)
16	Physical and psychological experiences	Opportunities for physically and psychologically beneficial activities, healing, relaxation, recreation, leisure, and aesthetic enjoyment based on close contact with nature
17	Supporting identities	The basis for religious, spiritual, and social-cohesion experiences; sense of place, purpose, belonging, rootedness or connectedness, associated with different entities of the living world; narratives and myths, rituals and celebrations; satisfaction derived from knowing that a particular landscape, seascape, habitat or species exist
18	Maintenance of options	Capacity of ecosystems, habitats, species or genotypes to keep human options open in order to support a later good quality of life

(e.g., boats and fishing gear, or farm equipment), human labour, and institutions. Institutions can facilitate or prevent access to resources and are often important for determining whether or not potential NCP generates realized NCP. For some regulating services, the degree to which potential NCP generate realized NCP depends on environmental conditions. For example, a forest or grassland may have capacity to filter pollution, but the realized NCP of pollution removal will depend on the amount of pollution coming into contact with the ecosystem. For non-material NCP, an ecosystem may have the potential to support recreation and tourism but if people do not actually go there then it will not yield realized experiences (NCP 16).

For some NCP, there is a further distinction between realized NCP and output, which occurs when what people care about differs from realized NCP. For example, the realized NCP of "regulation of freshwater and coastal water quality" (NCP 7) measures how ecosystems filter nutrients and pollutants from water. Water quality, which is what people care about, depends upon both the input of nutrients and pollutants into the water as well as water filtration provided by ecosystems. If pollution upstream increases, the realized NCP of filtration may increase even though water quality may decline. There may also be a difference between realized NCP and output because of substitutes. For example, food can be produced from natural systems and modified natural systems (e.g., agroecosystems), but food can also be produced in heavily-engineered systems, such as hydroponic production.

The final link moving from left to right in **Figure 2.3.1** is between outputs and impact on good quality of life. Impact on good quality of life depends upon institutions that affect access and use, and upon culture that influences how people perceive, use, and value outputs. Human-made substitutes may influence how the output of NCP impact good quality of life. For example, high quality drinking water can be realized through intact ecosystems that filter nutrients or through human-engineered water treatment facilities. Culture and institutions also mediate the relationship between outputs and impact on good quality of life.

The arrow moving from right to left in **Figure 2.3.1** illustrates how human actions influence potential NCP by altering nature via direct drivers, such as ecosystem management, land-use change, or climate change, the choice of inputs that affects realized NCP, and substitutes for NCP on good quality of life. Information about how human actions influence nature, inputs, or substitutes, and how these in turn impact NCP and impacts good quality of life, can be used to guide human management to ultimately improve quality of life.

To emphasize the intertwined influence of nature and society on the status and trends of NCP, this section uses the term "co-production" to describe how nature and people jointly determine the provision of NCP (Díaz *et al.*, 2015; UN, 2014). For example, a natural medicine requires both that the natural resource is available, and that people have the knowledge to identify and use the healing properties of resources (see NCP 14). The intertwined influence of nature and society is also shown in **Figure 2.3.1**, with nature contributing to potential NCP and human contributions influencing both realized NCP and outputs.

The concept of NCP builds on the concept of ecosystem services (Daily, 1997; Ehrlich & Mooney, 1983; MA, 2005). The IPBES conceptual framework (Díaz *et al.,* 2015) of NCP and its connections to good quality of life shares many similarities with prior ecosystem service frameworks (e.g., Daily *et al.,* 2009; Guerry *et al.,* 2015; Potschin & Haines-Young, 2011), but there are several differences in reasoning and emphasis. In comparison to the discussion of ecosystem services in the Millennium Ecosystem Assessment (MA, 2005), the discussion of NCP emphasizes the central role that culture plays in defining NCP, in different conceptualizations of nature, in human-nature relationships, and in knowledge systems, especially the complementarity between scientific, indigenous, and local knowledge (chapter 1; Díaz *et al.,* 2018). The concept of NCP, as discussed here, also emphasizes the distinction between potential and realized NCP, with realized NCP emphasizing the integration of inputs from humans and nature to co-produce NCP. The discussion of NCP notes that both potential and realized NCP may differ from outcomes. Much of the prior work emphasizes the contributions of nature through ecological functions that supply benefits to people without the emphasis on co-production.

Though many of nature's contributions are positive, there are also negative impacts (similar to ecosystem disservices), such as when elephants trample agricultural crops or mosquitos spread disease (Saunders & Luck, 2016; Shackleton *et al.*, 2016; Vaz *et al.*, 2017). Some ecological interactions simultaneously provide positive and negative contributions. For example, pests feeding on plants are a disservice to food production, but ecological and evolutionary plant responses to these pests are the source of biochemical compounds that have nutritional values, flavour our foods as spices, and are used as medicines.

To support the analyses of these interrelationships, literature evaluating each NCP was evaluated as described in section 2.3.5. The rest of this chapter is divided into five subsections. Subsection 2.3.2 builds on the discussion of **Figure 2.3.1** and provide greater depth on the numerous nature-human interactions on which NCP depends. Section 2.3.3 reviews the concepts and methods for analysing the co-production of NCP. Subsection 2.3.4 reviews concepts and methods for analysing the social, cultural, economic, and political factors that combine with NCP co-production to impact good quality of life. Subsection 2.3.5 is the heart of the chapter and reviews empirical evidence on status and trends of NCP co-production and impact of NCP on good quality of life. Subsection 2.3.6 contains concluding remarks. Detailed assessment of the status and trends for each NCP are included in Supplementary Materials, Appendices 1 and 2.

2.3.2 NATURE AND PEOPLE INTERACT TO CO-PRODUCE NCP AND GOOD QUALITY OF LIFE

Nature and people have always been interconnected in innumerable ways, but awareness of the global implications of such interactions has only become evident in recent decades. Earlier sections of this chapter on Drivers (chapter 2.1) and Nature (chapter 2.2), and chapter 1, illustrate that the actions of people have been affecting nature in numerous and profound ways, from local to global levels. In turn, the literature on ecosystem services and the NCP framework used here focus on the many ways that nature contributes to good quality of life. These efforts to understand the contributions of nature to people fit into a larger context. Literature on social-ecological systems (Berkes *et al.,* 1998; Folke, 2006) and coupled human and natural systems (Liu *et al.,* 2007) have emphasized the co-dependence and co-evolution of people and nature in integrated, complex systems composed of both social (human) and ecological (biophysical) elements. They highlight the feedback between people and nature that shapes both. The importance of these feedbacks has become increasingly apparent as we become aware of the global scale-impact of human activities. Human actions are not only a major driving force of environmental change but the source of change in earth system functioning (Crutzen, 2002), which in turn increasingly affects important aspects of local quality of life (Ellis, 2018; Steffen *et al.,* 2015).

Co-production of food and feed (NCP 12), particularly crop and animal domestication, provides a clear example of the interconnections of nature and people. Domestication is based on an interactive process: wild plants and animals influence human understanding, and people select and domesticate plants and animals (Larson & Fuller, 2014; Olsen & Wendel, 2013). People have selectively bred and dispersed species that have subsequently evolved separately from their wild relatives, allowing agriculture to flourish while fundamentally reshaping human societies and their environment (Stépanoff & Vigne, 2018). The process of co-production uses and creates learning and transmission of knowledge (classifying and naming nature elements, management), experimentation (identifying agronomic or nutritive properties), and decision making (selection of useful traits) (Larson & Fuller, 2014; Stépanoff & Vigne, 2018). Knowledge and practices from Indigenous Peoples and Local Communities (IPLCs) have contributed greatly to domestication and food production; a wide diversity of crop varieties and animal landraces have been developed locally by IPLCs (Altieri *et al.,* 2015). Institutions and governance play a critical role in how crop varieties and knowledge about them are transmitted, and, in turn, these institutions have been shaped by domestication and food production. Institutions and governance range from reciprocity networks based on social exchange and interaction (Coomes *et al.,* 2015; Pautasso *et al.,* 2013) to gene editing technologies so new that regulatory frameworks about ownership have not yet been created (Wolt *et al.,* 2016).

The current state of nature is an important, but not the sole, determinant of quality of life (Guerry *et al.,* 2015; Joly, 2014; Raudsepp-Hearne *et al.,* 2010b). In fact, most contributions from nature to good quality of life derive from interactions between nature and people, including the use of various types of anthropogenic assets, along with the institutions that govern their access, use, and distributive benefits (UN, 2014). Anthropogenic assets include built infrastructure, machinery, and structures, as well as knowledge (including

Table 2 3 2 **Examples of the Functions of Institutions.**

Provide rules regulating property rights for users, management rights, and distributive benefits	Define forms of sanctions and conflict resolution mechanisms
Spread costs	Bring together social, financial, and institutional resources
Achieve economies of scale	Determine needs on a broad scale
Attract expertise	Assess risk
Achieve competence	Apportion and augment NCP
Perform oversight and resource monitoring	Perform quality control
Set prices for non-market goods	Maintain and improve infrastructure
Address non-market social needs	Guiding private enterprise/markets

indigenous and local knowledge systems, technical or scientific knowledge, formal and non-formal education, and experience), technology (both physical objects and procedures), and financial assets. Governance institutions, cultural and spiritual beliefs, and practices can also influence and shape NCP.

Fisheries provide a good example of the complex interactions of nature and people that determine the impact of nature's contribution to good quality of life. The contribution of a fishery to the quality of life of a coastal community depends on interactions between fish abundance, local fishing assets, and the institutions setting rules and norms for access and distribution of fish. Fish abundance itself depends upon the health and productivity of marine and coastal ecosystems and on past fishing activity that impacted marine and coastal habitats and the abundance, diversity, and evolution of fish populations and communities (e.g., Berkes, 2012; Schindler *et al.*, 2010). In addition to fish abundance, the contribution of the fishery to quality of life depends on the effort, knowledge, and experience of the fishers, their fishing equipment (boats, nets), and their economic organization and culture that helps to determine the value and importance of the fish harvest to the community. In addition, institutions and governance that determine access and distribution of benefits play a key role in ensuring long-run sustainability of the fishery and the community (Costello *et al.*, 2008; Gutiérrez *et al.*, 2011; Ostrom, 1990). Some of the important roles that institutions play are listed in **Table 2.3.2**.

2.3.2.1 Co-production of NCP by nature and people

Co-production describes how nature and human management combine to make various NCP available. While acknowledging the critical role of abiotic factors such as topography and climate, the focus here is on the contribution that living nature makes in affecting the availability of NCP.

Human management that affects ecosystems offers a rich set of options for maintaining and improving the co-production of NCP. Such management practices include ecosystem restoration, moderating human actions to be less destructive of ecosystem processes important in the co-production of NCP, and biodiversity-rich agroecosystems that maintain ecological processes. Management actions can also facilitate and enhance co-production of NCP, such as adding filter strips between farms and waterways, designing agricultural systems that maintain crop evolutionary processes and high level of associated biodiversity, replanting grasses to stabilize sand dunes, and xeriscaping. Human management can benefit by borrowing ideas from nature and using them in different applications, such as installing green roofs, use of chemical compounds from nature to produce new medicines, or the invention of new products through biomimicry. However, some human actions, such as emissions of air and water pollutants or conversion of natural habitat for human dominated land uses, negatively impact ecosystem processes and damage or degrade the potential for providing NCP. Such negative impacts may be the unintended consequences of human actions, but often they result from decisions favouring some types of contributions at the expense of others. Specific outcomes or activities are often privileged, and in producing those outcomes others may be negatively affected, often those which are diffuse, less valued culturally or economically, or valued by a less powerful group of users. For instance, a given constituency may live with high levels of pollution or deforestation in exchange for increased revenue from commodity crops or increased industrial employment, even if pollution and deforestation affect large sectors of society and limit future opportunities.

Changes in nature affect the co-production of NCP through a variety of pathways. Conversion of habitat (e.g., deforestation), land-use patterns (e.g., fragmentation resulting in smaller forest patches), and changes in human use (e.g., increase in hunting animals or gathering plants) all affect the co-production of NCP. For example, above-ground carbon sequestration for climate regulation (NCP 4) is primarily a function of vegetation biomass, so changes that affect biomass affect climate regulation (Pregitzer & Euskirchen, 2004). Change in NCP co-production may occur even if human management is low impact; footpaths can be the most active run-off-generating feature of inhabited montane landscapes (Harden, 1992), potentially affecting the regulation of water flow (NCP 6). Some NCP are highly dependent on specific species or communities. Co-production of food (NCP 12), for example, requires specific edible and appealing species (e.g., grapes for wine production) and genetic diversity (e.g., different varieties of grapes) for dietary, cultural, and economic reasons.

There is considerable diversity in how different groups integrate ecosystem processes with human actions to co-produce NCP. Many indigenous and non-indigenous societies, referred to in this report as Indigenous Peoples and Local Communities (IPLCs), consider themselves to be integrated elements of nature and nature as an integrated element of culture (Descola, 2013; Sanga & Ortalli, 2003). Because indigenous territories represents ~38 million km^2, over a quarter of the world's land surface (Garnett *et al.*, 2018),and at least twice the area if local communities are considered (see chapter 1), IPLCs managed landscapes generate many and diverse NCP. Other social groups, such as farmers and herders in both high and low income countries, depend closely on nature but may vary in their interactions with nature in their level of use of anthropogenic assets, particularly technology. At the other end of the spectrum, there are many groups whose livelihoods depend only indirectly, albeit equally fundamentally, on nature and whose local environment is largely transformed by human interventions, such as many urban dwellers, who depend on the continuous, mostly external, flow of water and food.

There is substantial interaction among NCP, as they are often jointly produced. Trade-offs among NCP co-production can occur when exploitation of one NCP changes nature in such a way that other NCP are negatively affected. For example, conversion of forests or grasslands to cultivated cropland increases food production (NCP 12) but can reduce carbon storage (NCP4), change water distribution and quality regulation (NCP 6 & NCP 7), and reduce pollination (NCP 2) and pest control (NCP 10), negatively affecting agriculture itself (Power, 2010). Agricultural intensification may also negatively impact the diversity of resources, which reduce ability to learn from nature (NCP 15) and will tend to reduce options for future use (NCP 18). Synergies also exist, such as co-production by urban parks of storm water control (NCP 6 & NCP 7), reduction of the urban heat island (NCP 4) and improved mental health (NCP 16) (Keeler *et al.,* 2019).

For some NCP, whether an increase in a measure of co-production is good or bad tends to be consistent across user groups. Increased regulation of pests (NCP 10) benefits agriculture and reduces vector-borne disease. For other NCP, whether an increase is desirable or not depends on conditions and on who the beneficiaries are. Natural infrastructure that reduces downstream flooding (NCP 6), for example, might be positive if damage to streamside homes is decreased but negative if floodplain agriculture is starved of sediment and nutrients delivered by flood waters. The effectiveness of NCP co-production should be evaluated in comparison to the co-production of NCP under an

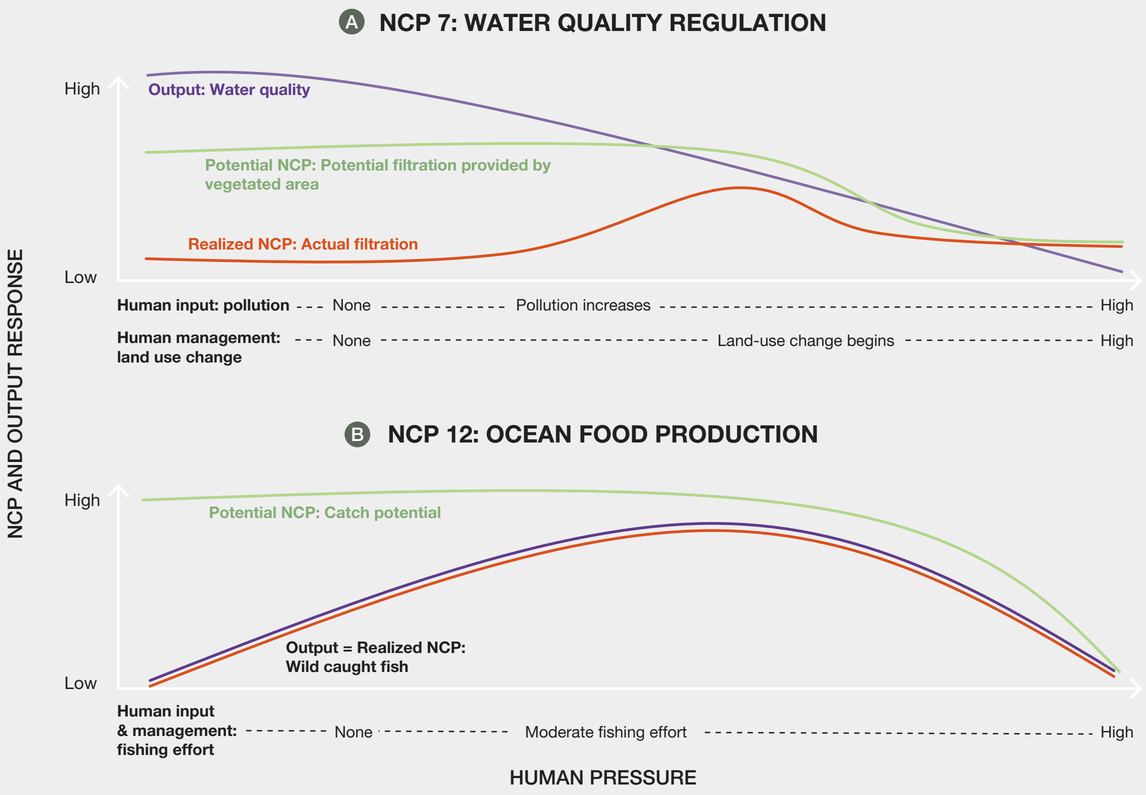

Figure 2 3 2 **Response of Potential NCP, Realized NCP, and NCP Output to External Pressures.**

Examples of changes in local co-production of potential NCP, realized NCP, and the output as human pressure increases. In A, pollutant load increases from left to right, as does land use change. The potential of nature to filter water (green line) decreases as people convert vegetation. Realized water filtration (red line) is low at the left, because there is no pollution to filter. As pollution increases, realized water filtration increases. As land use change decreases potential filtration, realized filtration also decreases. Eventually land use change ceases; water quality continues to decrease as pollution increases because realized filtration has saturated. Extremely high pollution loads could also degrade the potential NCP. In B, fishing effort increases fish catch, which is both the realized NCP and the output. As fish catch increases, catch potential, the potential NCP, decreases, and realized NCP drops as a result.

alternative landscape or management approach (Brauman, 2015). For example, in a vulnerable geography, a large storm will cause a storm surge regardless of the condition of coastal habitat, but differences in the severity and extent of flooding could be attributed to intact mangroves or seagrass beds (NCP 9) as well as to the distribution of human assets (Arkema *et al.,* 2017).

Co-production of both potential and realized NCP change in response to human drivers **(Figure 2.3.2)**. For example, conversion of vegetated land to paved surfaces or bare soil reduces the potential for natural water filtration (NCP 7), and management to improve the functional composition of filtering vegetation or building artificial treatment wetlands increases the potential NCP. Realized NCP changes in response to both potential NCP and human inputs. For example, if there is little pollution in water, vegetation removes very little pollution, and so the realized NCP of actual water filtration is small. As the human input to water pollution increases, so does filtration, but only to a point (Bouwman *et al.,* 2005; Smith *et al.,* 2003; see Appendix 2-NCP7). Changes in the output, water quality, are a function of both changes in land management that change the potential of a landscape to filter water and changes in human inputs of pollution. Even if realized water filtration is large, pollutant loads could still overwhelm filtration capacity, leading to low quality water. Similarly, for provision of food from the ocean (NCP 12), potential catch is a function of ocean productivity, which is related to both the natural system and human management including fishing itself. Realized catch of wild fish changes with both potential catch and the amount of fishing effort. Realized catch increases with fishing effort but decreases as overfishing causes the potential NCP to decline. In this case, output and realized NCP are the same – amount of wild-caught fish (see Appendix 2-NCP 12).

2.3.2.2 Anthropogenic substitutes for NCP

Anthropogenic substitutes for NCP are human-created or human-mediated processes that provide alternative ways to satisfy human needs and desires that partially or completely replace an NCP. For example, water filtration facilities can substitute for water purification provided by ecosystems (NCP 7) in providing clean drinking water (e.g., Ashendorff *et al.,* 1997; National Research Council, 2000). Substitutes could replace the NCP of pollination (NCP 2), such as when hand pollination replaces wild pollinators (Garibaldi *et al.,* 2013). Substitution for pollination could also entail replacing agricultural crops that require animal pollination with crops that do not. A good substitute for an NCP is characterized by its ability to match or exceed the contribution of the NCP, including consideration of changes in access and redistribution of benefits across different user groups, without incurring additional cost. What may be a sufficient substitute for some, for example artificial flavours and fragrances, may result in a significant loss in the contribution to good quality of life for others with different cultural values and preferences.

For some NCP, there may be no good substitutes. 'Critical natural capital' is comprised of components of nature that contribute to good quality of life for which there are no good substitutes so that loss of these components necessarily implies a decline in quality of life (Ekins *et al.*, 2003). For example, the loss of a forest or other natural habitat might cause a loss of identity or sense of place for people for whom the forest had special meaning or significance (Olwig, 2004; Plieninger *et al.*, 2015b). Even when substitutes exist, they may be imperfect or impose significant costs. For example, loss of nutrient filtration capacity of ecosystems may require expensive water filtration facilities downstream to provide clean drinking water (Chichilnisky & Heal, 1998; National Research Council, 2000). In the design of new drugs, use of natural compounds known to be active in traditional medicine can be a more efficient starting place than invented de novo compounds (Newman & Cragg, 2012).

Imperfect substitution may arise because components of nature jointly contribute to multiple NCP. Human-engineered substitutes can often be designed replace a narrowly defined function of nature, but these may fail to replace all natural functions that contribute to a range of NCP. For example, declines in wild pollinators have impacts on plants well beyond crops and may cause declines in plant species that depend on pollination as well as other species that depend on those plants (Brodie *et al.*, 2014; Potts *et al.*, 2016).

Recognizing that the future may be different from today in surprising ways argues for preserving options for the future (NCP 18). A precautionary approach to ecosystem manipulation is often the best way to maintain a full array of potential and realized NCP. The future co-production of NCP may depend on the maintenance of current genetic and evolutionary diversity within and among species.

2.3.2.3 Impact of NCP on good quality of life

The impact of NCP on good quality of life depends both on co-production, which determines the availability of NCP (reviewed above), and on numerous cultural, social, economic, political, and institutional factors that determine how NCP are accessed and utilized and their importance and value to people. Even with the same access to NCP, the impact on good quality of life may be quite different for different groups of people. Groups with different culture, history, experience, education, income, or other factors may use and value NCP quite differently (e.g., Díaz *et al.,* 2018; Pascual *et al.,* 2017). Different cultures may also view nature as contributing to different categories of NCP. For example, the harvest of animal or plant species may contribute to material standard of living by providing nutritious food or providing raw materials for clothing or shelter, while particular animals and plants play a central role in cultural identity or spiritual practices in certain cultures but not others.

Distribution among groups in society

An important question in discussing the impact of NCP on good quality of life is impact on whom. Though overall trends in NCP, and the aggregate value of NCP, are important for policymaking, understanding the distribution of impacts of NCP on the quality of life for different social groups is critical to address social justice concerns (Adekola *et al.,* 2015; McAfee, 2012; McDermott *et al.,* 2013). Nature's contributions affect major social groups in different ways, with some specific contributions being much more important for some groups than others. For example, changes in pollination (NCP 2), pest regulation (NCP 10), and soils (NCP 8) are of greater importance for commercial farmers, while regulation of freshwater quality (NCP 7) and regulation of ocean acidification (NCP 5) are of greater importance for commercial fishers. For many combinations of NCP and major social group there is considerable heterogeneity of impacts by region, and even for different groups even within the same region (e.g., different income classes or ethnic groups).

Impact on good quality of life may occur far from where an NCP is co-produced, and preferences and governance in distant societies may affect co-production. Globalization and trade moves goods that are co-product in one region to consumers around the globe. People living in urban areas rely on food, materials, and medicinal products (botanical medicines) that are produced or grow naturally thousands of miles away. Global nature tourism influences the management of some nature conservation areas. Demand from far away can increase pressure on ecosystems and have detrimental impacts on the local environment and on co-production of NCP (Chi *et al.,* 2017; Wolff *et al.,* 2017). A number of recent analyses study the environmental impacts of trade by tracking the carbon embedded in traded goods (e.g., Davis & Caldeira, 2010; Peters *et al.,* 2012, 2011; Sato, 2014) or the amount of water embedded in traded goods (e.g., Allan, 2003; Dalin *et al.,* 2012; Hanasaki *et al.,* 2010). Flows of resources both direct (e.g., commodities) and indirect (e.g., virtual water) can shift the burden and benefit of NCP co-production to distinct communities (MacDonald *et al.,* 2015). Other linkages between co-production in one region and impact on quality of life occur because of environmental interconnections. For some regulating NCP, impacts are global, such as climate regulation (NCP 4). For other NCP there are important impacts downwind (air quality regulation, NCP 3) or downstream (water quantity regulation, NCP 6, and water quality regulation, NCP 7).

The way people benefit from nature depends on where and how they live and how institutions support or inhibit access to NCP. Though overall trends in NCP, and the aggregate value of NCP, are important for policymaking, understanding the distribution of impacts of NCP on the quality of life for different social groups is critical to address social justice concerns (Adekola *et al.,* 2015; McAfee, 2012; McDermott *et al.,* 2013). Knowing how changes in NCP differentially impact disadvantaged social groups, such as subsistence harvesters in tropical forest regions or low income peri-urban residents, can help devise more effective strategies for poverty alleviation. Disadvantaged groups in regard to NCP refer to those groups who have less access to nature and to different types of anthropogenic assets (i.e., forms of capital: natural, human, manufactured, social, financial capital) that allow them to benefit from nature. The distribution of NCP strongly affects the quality of life of disadvantaged social groups in societies with strong power asymmetries. For this reason, a greater disaggregation of social groups to better understand the distribution of NCP is needed, particularly where levels of inequality are high (Daw *et al.,* 2011).

Factors leading to unequal distribution of NCP include geographic location, nearness of nature, social status hierarchies and power relations, property and access regimes, and availability of anthropogenic assets needed to co-produce NCP. Property and access regimes are types of institutions with strong influence on NCP distribution. Recent research has emphasized the multiple mechanisms by which social groups gain access to nature and benefit from NCP, beyond formal institutions, notably property rights (Cole & Ostrom, 2010). Whether land is either or a combination of private, public or common property, rights interact with the biophysical context to shape basic access to nature and NCP. Furthermore, social groups may gain complementary access through their differential ability to access anthropogenic assets such as knowledge and technology, and different groups have varying power to impose their choices, such as the ability of influential groups to modify institutions (Ribot & Peluso, 2003). This in part explains why formal and informal institutions ("rules-in-use") often work against disadvantaged groups and limit how much these groups can benefit from nature (Seghezzo *et al.,* 2011).

A spatially explicit analysis of NCP along with access rules and infrastructure can help to identify which groups will likely benefit the most from co-production of NCP. Some analyses have linked provision of NCP to beneficiary groups (e.g., Bagstad *et al.*, 2014). It is important to note that human use of ecosystems creates feedbacks that modify landscapes and affect the availability and accessibility of NCP beyond immediate users and for the future. Knowing who wins and who loses due to changes in the co-production of and access to NCP, and the mediating role of institutions and governance regimes, is a highly policy relevant area of research that requires strong interdisciplinary science.

Characteristics of user groups mediate the impact of NCP on good quality of life

A fully developed analysis of the impact of NCP on good quality of life would report on the consequences for specific user groups. User groups could be based both on livelihoods (subsistence gatherers, subsistence and commercial farmers, subsistence and commercial fishers, pastoralists, commercial ranchers, commercial foresters, mining, energy production, commercial and manufacturing), as well as residence location (rural, semi-urban, urban, coastal, inland, forest, grassland, desert, etc.), or other forms of social categorization. Studying the impacts of NCP on quality of life, as well as doing so by major user group, is still a relatively new area of research. There are many gaps in our knowledge base and information to report on trends by user group is quite limited for many NCP. Though this was the initial goal of this assessment, there was insufficient evidence reported in the literature at present to support a comprehensive and systematic reporting of the impacts of NCP on good quality of life by different user groups.

Issues in aggregating data and information on NCP across and within groups

A global level assessment requires aggregate information. For NCP, 'aggregation' refers to assessing the benefits of NCP to a large group without explicit recognition of distributional patterns of benefits within the group. Reporting the aggregate monetary value of NCP at a national or global level contains useful summary information and can be helpful for seeing broad scale trends. However, reporting aggregate value also hides information about distribution of NCP impacts among groups and be poor indicators of the contribution to poverty alleviation (TEEB, 2010). Similarly, national aggregate indices of income (such as gross domestic product, GDP), do not address inequality variations in income and do not give proper attention to the condition of the poorest members of society (Piketty, 2014; Ravallion, 2001). Likewise, value reporting tends to overlook non-material NCP that are difficult to express in monetary terms.

One potential approach to taking account of distributional concerns but retaining the benefits of aggregation is to use equity weights that assign different values to different groups based on their relative wealth. Equity weights place a higher value on benefits to disadvantaged groups. Use of equity weights in climate change give greater importance to climate impacts in low income countries (e.g., Anthoff *et al.,* 2009; Azar & Sterner, 1996). To date, the literature on NPC has not used equity weights to analyse distributional consequences of changes in NCP. In general, there is a great need for analysis of NCP to take greater account of the distribution of impacts.

Distribution over time and discounting

Many changes to ecosystems have long lasting effects that can affect the flow of NCP for both current and future generations. Consideration of NCP values that occur in the future raises the issue of how to compare present versus future values. A standard approach in economics to questions of aggregating values over time is to use discounting but discounting for long-run environmental issues that affect quality of life for future generations also raises a host of ethical issues (Portney & Weyant, 1999; TEEB, 2010). The simplest and most common form of discounting is to use a constant exponential discount rate. However, many critics of discounting think that it puts too little weight on future values, especially those that occur in the distant future. A second issue with discounting is the lack of clarity on what discount rate should be used, as even slight differences in discount rates matter hugely. For example, the value of $1 million 100 years in the future is worth $6.7 thousand at a 5% discount rate but only $0.045 thousand at a 10% rate. Suggestions for discount rates range from greater than 10% for risky business investments to less than 1% for long-term investments in public goods that affect everyone. Several prominent economists have recommend using very low discount rates for projects with long lasting environmental impacts (e.g., Stern & Taylor, 2007; Weitzman, 1998) but other prominent economists have argued for use of much higher rates that are closer to market interest rates (e.g., Nordhaus, 2007a, 2007b). Most value estimates reported in section 2.3.5 are for the current value of NCP so discounting is not an issue. However, the issue is very important for management and policy decisions that affect the long run, such as with climate change or habitat protection policies.

Another issue is that the future NCP are not likely to be simple extrapolations of present NCP. For instance, elements of biodiversity might not provide an NCP in the present but may provide important contributions to good quality of life in the future. Such notions are at the heart of option value (NCP 18). Changing values, knowledge, and conditions, mean that NCP provided by the preservation of current biodiversity may only become apparent in the future.

2.3.3 METHODS FOR MEASURING CO-PRODUCTION OF NCP

Measurement of the co-production of NCP varies across studies and among NCP, as NCP are often evaluated in ways most relevant to their local context (Díaz *et al.*, 2018). For many NCP, studies of related biophysical or social phenomena exist but must be re-interpreted to evaluate their implications to NCP co-production. For example, the field of landscape hydrology is well developed but has generally focused on run-off prediction under various weather regimes, not specifically on the role of vegetation in regulating water flow (Brauman *et al.*, 2007). Similarly, much existing work in agronomy measures phenomena such as pollinator diversity or density without measuring the contribution of pollination to people, such as its impact on yield or nutritional value (Potts *et al.*, 2016). Even fewer studies consider interactions between multiple NCP (TEEB, 2015).

The impact of most NCP can be measured by ILK-based methods in addition to scientific approaches. Biocultural indicators simultaneously measure nature as well as practices associated with nature (e.g., species used for medicine, crops and their dietary roles, a forest and its role in protecting water sources). These indicators reflect how people benefit from nature for their well-being but also how humans contribute to ecosystem health or well-being (Sterling *et al.*, 2017b). These indicators also reflect how IPLCs engage in learning processes that contribute to co-production of NCP through knowledge generation (e.g., about the behavior of animals with importance as food, or changes in crop phenology that indicate climatic changes, or the development of crop varieties or landraces). These methods apply across all NCP and are addressed below in stand-alone section 2.3.3.2 to highlight the potential use of ILK to measure NCP.

Chapter authors systematically evaluated how co-production of NCP is measured following guidelines for systematic review (Collaboration for Environmental Evidence, 2013). Authors summarized theory of NCP co-production for each NCP in Section 2.3.3.1 (below) and in Appendix 2. Below, we group our findings about the approaches used to assess and measure NCP co-production in the literature into six major classes of scientific research and six approaches based on ILK.

2.3.3.1 Scientific approaches to measuring NCP co-production

Based on review of the literature on NCP and the biophysical and social processes that go into their co-production, we summarize six general approaches to measuring co-production of NCP.

i. *Biophysical processes*: Regulating NCP describe the influence of ecosystems and their biological constituents on biophysical processes that influence good quality of life. Direct measures of regulating NCP are usually difficult, as abiotic factors interact in the co-production of many regulating NCP. It is, however, often possible to measure specific biophysical processes important for NCP supply. These include measurement of air pollutants deposited on plant surfaces (NCP 3); carbon sequestered in growing forests (NCP 4) and algae (NCP 5); water transferred to the atmosphere or to aquifers by plants (NCP 6); changes in water quality attributable to filtering by riparian forests (NCP 7); the rate of soil erosion with and without vegetation (NCP 8); and root density that may stabilize rocks and soil on steep slopes (NCP 9). Models are frequently used to scale up local studies of biophysical processes and to integrate biophysical processes with other factors important for generating NCP.

ii. *Ecological interactions*: Some NCP are the outcome of ecological interactions, such as fruit and seed setting (NCP 2) and disease prevalence and crop damage (NCP 10); their production can be assessed based on the abundance and diversity of organisms involved in co-production, e.g., pollinators and seed dispersers (NCP 2); or pests, pathogens, predators, and competitors (NCP 10). These NCP can also be measured by the outcome of the ecological interaction. For example, the amount and quality of pollen deposited on the stigma (NCP 2) could be measured, as could impacts of pests in the presences of natural enemies (NCP 10). Outputs of co-production may also be evaluated, such as enhanced crop production (NCP 2) or reduced food waste (NCP 10).

iii. *Habitats and land cover types*: For many NCP, the presence of a specific habitat or land use type is interpreted to mean that an NCP is being co-produced. For example, hedgerows and forest fragments alongside farms are assumed to provide pollination (NCP 2) and riparian buffers to provide water filtration (NCP 7). Assumptions about land cover functionality are generally extrapolated from local studies that measure a biological process or identify particular organisms or the outputs of ecological interactions.

iv. *Direct material use of organisms*: Material NCP are based on the direct use of organisms to provide for material human needs. Material NCP include bioenergy (NCP 11); food (NCP 12); materials (NCP 13); and medicine (NCP 14). Realized material NCP can be directly measured through the amount and quality produced or consumed; potential NCP can be measured as the extent and suitability of land, freshwater, or marine areas for production, as well by the diversity of organisms with potential use for material human needs.

v. *Human experience and learning*: Non-material NCP stem from the interactions of people with material and non-material elements of nature. Measures of the interactions between people and nature, such as proximity of people and nature in everyday life (NCP 15), tourism and recreation in outdoor areas (NCP 16), or customary or ritual use of sacred sites (NCP 17), are one way of quantifying them. Proxies may also be used, such as the economic value of patents resulting from bio-based innovations (NCP 14), the use of bio-inspired materials (NCP 15), co-existence of cultural (linguistic) and biological diversity (NCP 15), investments in equipment for outdoor activities (NCP 16), and time since major land use change (NCP 17). These proxies are not thought to be representative but represent early attempts to quantify non-material NCP.

vi. *Diversity of life on earth*: A diversity of organisms and ecosystems are required to co-produce NCP. Diversity can be assessed using metrics such as phylogenetic diversity and intra-specific diversity to quantify biological variation that underpins the provision of options for the future (NCP 18).

NCP measures are relatively consistent in some cases (e.g., NCP 4 carbon sequestration), but for many NCP there are no globally consistent data on which to base estimates of status and trends (Crossman *et al.,* 2013). Specific methods for assessing NCP are still evolving, tend to be locally relevant, and as a result are often difficult to compare globally (Díaz *et al.,* 2018). Measurements of regulating NCP are inconsistent among studies and thus difficult to compare (Ricketts *et al.,* 2016). For material NCP, measures of realized co-production are more robust, largely because many associated NCP have sales and trade data, though these may not reflect NCP co-production important to IPLCs and other marginalized or less visible communities. Moreover, these data do not provide information about potential NCP because they fail to reflect unsustainable resource harvest or NCP quality (Hein *et al.,* 2016). For non-material NCP, qualitative approaches assessing human experiences and learning from nature are deeply informative and are generally locally specific and highly contextual, again making comparison among studies difficult (Daniel *et al.,* 2012; Milcu *et al.,* 2013; Pascual *et al.,* 2017; Satz *et al.,* 2013). At the global level, non-material NCP are often measured by proxies representing the state of nature that contributes to experience and learning, such as extent of high biodiversity landscapes or existence of sacred sites (Berkes, 2012; Garnett *et al.,* 2018; Verschuuren *et al.,* 2010).

2.3.3.2 Indigenous and Local Knowledge approaches to measuring NCP co-production

Indigenous Peoples and Local Communities have long histories of observation, experimentation, prediction, testing, investigating causality, and interpretation and explanation (Cajete, 2000). In comparing indigenous science with western academic science, the Worldwide Indigenous Science Network remarkss "'Indigenous scientists are an integral part of the research process and there is a defined process for ensuring this integrity" (Worldwide Indigenous Science Network, 2018). In general, indigenous practice emphasizes relational accountability to other people and to living and non-living things; making connections and understanding systems as a whole, including spiritual components, rather than through deconstruction into constituent parts; and seeking balance with the natural world rather than controlling it (Tengö *et al.*, 2017; Toledo, 2001). Relationality is the idea that relationships form reality, and relational accountability can be put into practice through choice of research topic, methods of data collection, the form of analysis, and the presentation of information (Wilson, 2008). In contrast to dominant science practices in which researchers stand outside the system as impartial observers, indigenous and other science perspectives acknowledge that there is an inextricable relationship between knowledge and the people and processes that produce it. This means that IPLC have unique insight into NCP, not only because they may have knowledge of NCP that differs from scientific approaches but also because they understand the co-production and impact of NCP differently. This has led to many studies showing that it is important to protect indigenous and local knowledge of NCP, the people themselves, and their ways of life if NCP are to be maintained (Friedberg, 2014; McGregor, 2004).

To measure NCP from an IPLC perspective, data about ILK of NCP co-production must must also be co-produced. This is done in a variety of ways, including participatory approaches, ethnographic research, participatory mapping, experimental economics, and social surveys (Alcorn, 1996; Ding *et al.,* 2016). Different types of dialogue workshops for the Americas, Asia-Pacific, Europe and Central Asia, and Africa dialogues, organized around IPBES assessments, have contributed to bring some of this knowledge to the assessment process through inviting a large set of representatives of IPLCs and researchers working jointly with the latter, and through facilitating a process of integrating their views and processes. Other sources of ILK measures of NCP has been conveyed in the scientific literature, scholarly and popular texts, and in reports by NGOs by and working with IPLCs. Broader recognition of the importance of ILK in environmental management, although greatly improved since the onset of the Convention on Biological Diversity in 1992 (article 8j), is still emerging. Global level syntheses of ILK contributions to co-production of NCP are scant because ILK is place-based and embedded in local cultural perspectives, so scaling up is challenging. However, integrating ILK with scientific approaches has allowed some important aspects of ILK to be upscaled. For example, although traditional agroforestry systems are locally based, global data mapping agroforestry systems across the planet (Zomer *et al.,* 2009) makes it possible to quantify the extent and impact of such practices at the global level. IUCN, through a process of dialogue and also systematic mapping, has produced global maps showing the diversity of sacred sites (Verschuuren *et al.,* 2010). Other examples include the management of regionally-relevant watersheds (Critchley *et al.,* 1994; Tsatsaros *et al.,* 2018; Wilson *et al.,* 2018) and the maintenance of agrobiodiversity of regionally and globally important crops and animals (Howard, 2010; Veteto & Skarbø, 2009).

ILPCs communicate their understanding of NCP co-production in a variety of ways, including:

i. *Nomenclature:* Names used in ILK designate species and intraspecific species diversity. Names communicate information about material NCP, their diversity and distribution across landscapes (e.g., crop diversity), and about non-material NCP, such as learning (e.g., phenology of each crop and its capacity to face water scarce situations, the names of specific pollinators and the species they prefer (Simenel, 2017), and predators of specific fruit trees). Compiling nomenclature can generate understanding of habitat intactness, distribution of a resource across a landscape, capacity of the latter to face risks and hazards, and drivers of change. Local lexicon may differentiate types and categories, for instance of food, medicines, and materials, and may also provide cues identifying species that are genetically distinct (learning NCP 15), have distinctive nutritional or medicinal qualities, or prefer a given environment. Work with local specialists, such as traditional healers, can provide precise information on threats to useful medicinal species (e.g., Ghimire *et al.,* 2008) and the drivers of change, specific areas that are more vulnerable, and species that are more vulnerable in relation to specific harvesting practices (Ghimire *et al.,* 2008). Linguistic analysis can indicate changes in biodiversity, including long-term changes. For example, reference to specific species in narratives and oral traditions in places where those species no longer exist indicate extinctions, and in some places this ILK indication of extinction has been associated with physical evidence of the loss of megafauna. Such evidence cross-checked with archeozoological archives and thorough linguistic analysis show that data from local narratives indeed correspond to periods of loss of megafauna as well as changes in human practices (Wehi *et al.,* 2018).

   ILK nomenclature also provides information about exchanges between proximate and distant social groups. For example, the pre-Columbian transfer of sweet potato varieties to the Pacific Islands by Amerindians from South America, was first established by linguists using IPLC terminologies who identified Quechua names used by Pacific peoples, a first finding that eventually led to scientific hypotheses tested genetically (Roullier *et al.,* 2013).

ii. *Narratives:* Narratives that relate the status of connections between plants, animals, fungi or soil microorganisms in ILK are a measure of biotic interactions which are often critical to the co-production of NCP. The narratives relate how connections are effectively favoured or used to identify functional roles of species directly or indirectly useful to people. These narratives generally link to co-production systems such as trees with symbiotic endomycorrhizae or ectomycorrhizae with fertilization roles on soils or that increase availability of carbon and water for the trees, and wild pollinators recognized for their specific roles (Couly, 2009; IPBES, 2016). Similarly, in the Mediterranean, biotic interactions between trees and ectomycorrhizae are understood through observation of the "brulé", a barren area located at the base of trees that host truffles, illustrate learning from nature (NCP 15) (Aumeeruddy-Thomas *et al.,* 2017). Narratives of infrequent events also provide a measure of hazards and the contribution of nature to mitigating hazard impact. These narratives collect observations of nature and NCP and transmit this information intergenerationally, a process that contributes to learning as well as mitigating hazards. For example, IPLCs in the Indian Ocean region drew from traditional myths and oral history about past tsunamis to identify ways in which nature helped mitigate tsunami impact and thus survive a recent disaster (Adger *et al.,* 2005; Arunotai, 2017; McAdoo *et al.,* 2006). IPLCs' narratives about ways nature can be managed to reduce the impact of past shocks include not only tsunamis (Becker *et al.,* 2008; Lauer, 2012; McAdoo *et al.,* 2009; Walshe & Nunn, 2012); but also fire (Bradstock *et al.,* 2012); extreme weather (Janif *et al.,* 2016); cyclones (Paul & Routray, 2013; Veland *et al.,* 2010; Yates & Anderson-Berry, 2004); floods (Mavhura *et al.,* 2013); heavy rain (Chang'a *et al.,* 2010; Roncoli *et al.,* 2002); and ENSO-induced frost (Waddell, 1975). Drawing on this place-based knowledge, 'hazardscapes' have been developed where the frequency, impact, and warning signs of hazards as well as the ways that nature mitigates hazard impact are documented through participatory techniques (Cronin *et al.,* 2004) and hazard mapping (Cadag & Gaillard, 2012; Tran *et al.,* 2009). In another example, comparative geological and linguistic analysis of Australian Aboriginal stories and narratives have showed that they include accurate information about sea-level rising floods occurring over 7,000 years ago (Nunn & Reid, 2016). As in science, understanding past events is important to predicting the future and to adaptation. More details about the relationship between ILK and hazard mitigation are provided in Supplementary Materials, Appendix 1.

iii. *Taboos and sacredness*: The presence of taboos or of sacred sites such as groves, landscapes, mountains, or objects indicate NCP ranging from direct material use to identity (Dudley *et al.,* 2010; Samakov & Berkes, 2017; Thorley & Gunn, 2008). For example, in Oceania, material and non-material contributions of marine resources are indicated by reef and lagoon tenure, which is used to manage access in defined territorial waters and serves to protect marine resources (Johannes, 1978). Similarly, concepts of taboo or (sacred) prohibition indicate human use of nature and are themselves manifestations of non-material benefits of nature (Bambridge, 2016a, 2016b; Conte, 2016; Dixon, 2016; Ottino-Garanger *et al.,* 2016; Torrente, 2016; Veitayaki, 2000). Recording taboos and sacredness in relation to nature elements is a measure of a given society's identity through intricate linkages to nature.

iv. *Practices of nature management.* IPLC practices, including changes in society and development of rules to address over-harvesting (Wehi *et al.,* 2018), also measure NCP co-production. For example, ILK practices to enhance pollination, ranging from fire management to strategic placement of crops, indicate the importance and extent of pollination (IPBES, 2016).

v. *Land use and land cover:* The existence of high biodiversity landscapes and sacred sites nurtured by ILK indicates the co-production of a wide range of NCP. These landscapes can be measured as land managed by IPLCs (Garnett *et al.,* 2018) as well as by detecting land use patterns such as large-scale agroforestry (Brondízio, 2008) or shifting cultivation systems (Heinimann *et al.,* 2017). The present-day composition of many ecosystems and culturally and economically important landscapes may also be a measure of ancient management by IPLCs; for example, anthropogenic soils (terra preta) formed by ancient Amerindians settlements suggests their knowledge of benefits provided by improving soil fertility (NCP 8) and also affects present-day Amazonian biodiversity (McMichael *et al.,* 2014). Measuring the geographic extent of practices and landscapes that ensue from past and present ILK activities is a key way to measure NCP. Contemporary soil management systems by IPLCs such as terraced cultivation landscapes in Asia, in high mountain areas, and in the Mediterranean region are areas where communities can explain how such practices contribute to soil improvements through decrease of erosion.

vi. *Direct elicitation*: IPLCs have spoken directly about their knowledge of NCP, especially during Dialogue workshops that were published regarding the 4 regional assessments. One such example is the role of Ficus species in agricultural areas in Madagascar; planting Ficus in fields increases agricultural productivity and overall biodiversity (Rafidison *et al.*, 2017). While describing such practices, traditional communities refer simultaneously to the ecological role of these trees, which attract many birds and lemurs, and also the connection to ancestors who planted them, and the power that they possess that can influence people's lives. Further, their leaves are often medicinal and their latex useful for hunting. 'ILK thus involves a holistic approach that does not separate the economic and tangible from the intangible and the overall ecological value. Because ILK tends to be holistic and consider social and ecological systems as interdependent, elicitation of values of nature are often linked to human-well-being. ILK, through elicitation of IPLCs often articulate and measure threats to NCP and their own well-being in an intertwined way because ILK understands interconnections between ILPC and nature and the impacts of nature on their lives in a holistic way that does not dissect one element and its specific use. ILK may thus measure changes in NCP by identifying processes that affect biodiversity and their lives concomitantly, including industrial development, forced displacement and migration, and climate change.

While scientific and ILK measures may seem distant depending on the type of question or goal, there are potential synergies between science and various types of indigenous and local knowledge systems. For example, agroforestry practices developed by and valued according to local ILPC measures also have high production outputs and may include carbon sequestration potential, both of which can be qualified and quantified in different but complementary ways (Altieri & Nicholls, 2012). Co-produced systems like agroforestry that provide critical NCP requires information about practices, such as soil management techniques, and how and where they are deployed, based on measures coming both from scientific research and ILK (Altieri *et al.,* 2015).

2.3.4 METHODS FOR MEASURING IMPACT OF NCP ON GOOD QUALITY OF LIFE

This section evaluates how different material and non-material relationships between people and nature influence the perception, importance, and value of NCP across social groups. Different societies and cultures, and different individuals within them, may consider their relationship to nature and the importance of various NCP in quite different ways. This leads to multiple dimensions of value, which are discussed in depth in chapter 1. We take a broad view of how value should be discussed and quantified. This requires mobilizing multiple methods to describe, characterize, and measure the value of nature's contributions to good quality of life. Value concepts can be expressed in terms of environmental (biophysical), economic, or social criteria, or in terms of specific outcomes such as health, income, or livelihoods. This section describes several approaches to measuring the value or importance of NCP, including methods that focus on biophysical measures with a clear link to quality of life, methods from the health sciences, methods from economics to quantify the market and non-market value NCP, and social, cultural, and holistic approaches to describing the impact of NCP on good quality of life.

2.3.4.1 Biophysical measures of NCP

Biophysical measures are often used to assess the co-production of NCP. Biophysical measures also can be useful for measuring impact on good quality of life as long they are clearly linked to measures of human well-being. For example, measures of the amount of natural habitat in agriculture are useful for predicting pollinator abundance, which can be linked to food production and improved nutrition. But for NCP with a complicated relationship between biophysical quantities and good quality of life, or that are valued quite differentially by different groups, biophysical indicators only provide a partial measure of the impact on good quality of life. For example, increases in water flow may be good or bad depending upon whether there is currently water shortage (drought) or excess water (flood) affecting different groups of people. Another challenge is that biophysical measures may have course spatial resolution that does not include indicators grounded in indigenous and local knowledge better able to capture local needs (Sterling *et al.*, 2017a). For example, a measure of water quality cannot capture Maori values such as the role of particular water bodies in creation stories, maintaining local species habitats, used in access routes, or potential use by future generations (Harmsworth *et al.*, 2016).

Even when a biophysical measure is clearly tied to an impact on quality of life, the biophysical measure alone rarely is sufficient for describing the value of the NCP (Martín-López *et al.,* 2014). For example, knowing how intact ecosystems can reduce flooding potential downstream is an important component of the value of flood reduction. But without knowing the number of people exposed or impacted downstream the biophysical measure of the value of flood reduction is incomplete (Watson *et al.,* 2019). Also, biophysical measures should account for changes in the relative scarcity of nature. NCP that become scarcer over time relative to human-made substitutes will become more valuable (Drupp *et al.,* 2018; Krutilla, 1967).

Careful thought is required to translate biophysical measures into measures of impact on people and their quality of life (Keeler *et al.,* 2012; Polasky & Segerson, 2009). Olander *et al.* (2018) describe the development of benefit relevant indicators (BRIs), which are well-defined measures of outcomes valued by people because they have a direct impact on well-being. Some biophysical measures, such as those relevant to human health, make good benefit relevant indicators because they have clear value to people and may also encapsulate several aspects of quality of life at once. Epidemiological models can be used to translate environmental exposures to pollutants into health risks. Such methods have been applied to assess the health benefits of reduction in exposure to air pollution (e.g., Arden Pope & Dockery, 1999). For many biophysical measures, however, there are several intermediate steps needed to translate the biophysical measure into a measure of impact on human quality of life. For example, the contribution of an ecosystem to nutrient filtration can be measured in biophysical terms by the reduction in nutrient loadings to water bodies. But information about nitrate loading alone is insufficient for understanding impacts on human health. Translating nutrient loadings to impacts on quality of life also requires knowledge of how changes in nutrient loadings affect water quality (levels of nutrient concentrations), how people use water downstream (drinking water, irrigation, recreation, etc.), and how nutrient concentrations affect these uses (e.g., whether for drinking water there is a water treatment plant that removes excess nutrients prior to drinking so that extra nutrients increase cost, or are there health effects from drinking lower quality water). In addition, current biophysical outputs do not necessarily represent future biophysical outputs. For example, climate change may cause changes in precipitation patterns and run-off leading to different nutrient loadings with consequent impacts on various downstream uses (Runting *et al.,* 2017).

Another disadvantage of using biophysical measures is that it can be hard to compare impacts involving multiple NCP.

Assessing and comparing the impact on good quality of life of different outcomes of co-production typically requires either measuring outcomes in the same unit or knowing people's preferences for alternative outcomes (Mastrangelo & Laterra, 2015). For example, clearing land to plant crops will increase food production but often results in lower water quality and reductions in carbon storage. Whether this increases or decreases overall value depends on the relative value of food versus water quality and carbon storage. Biophysical measures are essential to support evidence-based decision-making but are not able to fully capture diverse value systems.

In sum, biophysical measures are essential for defining potential NCP, realized NCP, and output, but need to be clearly linked to human well-being in order measure to impact on good quality of life. But biophysical measures alone are rarely sufficient for evaluating impact on good quality of life. In section 2.3.5, we combine biophysical measures with measures of human use to define impact on good quality of life.

2.3.4.2 Contributions of NCP to Health

NCP impact health through: (1) dietary health, (2) environmental exposure, (3) exposure to communicable diseases, (4) hazard risk reduction including exposure to extreme weather, drought or fire, (5) psychological health, and (6) use of natural compounds in medicinal products and biochemical compounds. For the first four risk factors, disability-adjusted life years (DALY) are frequently used to assess overall disease burden. DALY's are expressed as the number of years lost due to ill-health, disability or early death. The measure is becoming increasingly common in health impact assessments (Murray, 1994). Because risk originates from multiple interacting factors, including human drivers of environmental degradation, disaggregating the contribution of nature to reducing health risks remains highly complicated.

Diet: Diet related disease is the leading cause of premature mortality, both in terms of non-communicable diseases such as diabetes and cardiovascular illness, but also including hunger and starvation (Forouzanfar *et al.,* 2015; Wang *et al.,* 2016). Food production (NCP 12) and multiple supporting NCP are central to providing sufficient, healthy, delicious, and culturally relevant foods. While global food systems are able to produce sufficient calories for today's population (increase in NCP 12 production), many people do not consume a healthy diet. Lack of income leading to under-consumption continues to be a problem in many poorer areas while over-consumption leading to obesity is an increasing problem in many middle and upper income countries. Diet composition is also important. Increased consumption of fruits and vegetables is associated with reductions in various diseases such as cardiovascular disease (Ness & Powles, 1997). The diversity of global food supply is falling (decrease in the number of species supporting NCP 12; Khoury *et al.,* 2014; Lachat *et al.,* 2017)

Environmental Exposure: Environmental exposure includes the health risk associated with degradation of environmental quality. Notable health risks include air pollution (Cohen *et al.,* 2017) and water pollution, flagged as fifth and ninth in terms of global risk by the Global Burden of Disease respectively (GBD 2017 Risk Factor Collaborators, 2018). NCP do not account for totality of risk from poor air and water quality because much pollution originates from anthropogenic sources. Nature can filter out pollutants to some extent, though some recent studies show that nature can also concentrate and trap pollutants, which may occur with trees in urban settings (Keeler *et al.,* 2019). An increasingly small proportion of the global population depends directly on clean water provided by nature, and a decreasing number of freshwater bodies have water quality of sufficiently high standard for human consumption without treatment. Most air pollution comes from vehicle emissions, power generation; other industrial sources, agricultural emissions; residential heating and cooking; re-emission from terrestrial and aquatic surfaces; chemical processing; and natural processes (IARC, 2016). Emissions from agriculture, biomass burning, and natural processes are often exacerbated by loss of nature, suggesting an avoided cost of maintaining nature intact. Health impacts of exposure can be quantified by assessing population exposure to poor water or air quality metrics. Measures can include exposure risk levels or can be extrapolated to economic measures of avoided treatment cost or avoided mortality and morbidity (Viscusi & Aldy, 2003).

Exposure to communicable diseases and increased risk of contagion: Nature's contribution to exposures to communicable disease and reductions in exposure is mixed. Habitats and alteration of habitat affects the population of vectors of disease. Risk is highest when human populations are proximate to vectors or when they create environments that are conducive to vectors (e.g., creation of stagnant pools of water and increased risk of malarial infection). Disease risk increases when the vector and human habitat overlap such as is the case with human encroachment on forest systems for Ebola or the proximity of irrigated agricultural systems as with malaria. Risk maps can be developed which highlight localities where exposure risk is high (e.g., Anyamba *et al.,* 2009).

Hazard risk reduction: Environmental change, including climate change, is increasing human risk exposure to natural hazards (e.g., floods, fires), exposure to extreme weather events, and heat stress for outdoor workers (Guha-Sapir *et al.,* 2016; McMichael *et al.,* 2006). Intact nature can reduce risks by intercepting or buffering the impact of extreme events or by providing shelter or relief, described in NCP 9 (e.g., reduced wave or storm surge impact, reduced urban heat island effect that reduces heat exposure for urban residents). At times, however, change in nature in response to environmental change can increase risk (e.g., climate change driven fires increase exposure to poor air quality, loss of life to fire, and delayed risk of mass erosion driven by loss of soil retention). Specific measures include the direct loss of life due to a hazard in question. Contributions can be assessed by evaluating nature's contributions to reducing loss of life or to the value of property damage (Barthel & Neumayer, 2012).

Psychological well-being: Interaction with nature are hypothesized to improve mental health (Frumkin *et al.,* 2017), though reviews of scientific findings have been inconclusive about the extent of this effect and the elements of nature which might provide it (Gascon *et al.,* 2015; Haluza *et al.,* 2014; Lee & Maheswaran, 2011). Exposure to the outdoors does likely improve learning and well-being for children (Gill, 2014; McCormick, 2017; Tillmann *et al.,*

Box 2 3 2 **Human health and microbiota.**

Microbial organisms living in and on the human body (in the gut, oral and nasal cavities, and reproductive and respiratory tract), collectively known as microbiota, carry out a range of vital functions and are a key determinant of health (Belkaid & Hand, 2014; Rodrigues Hoffmann *et al.,* 2016; Thomas *et al.,* 2017; Turnbaugh *et al.,* 2007; Wang *et al.,* 2017; West *et al.,* 2015). These organisms (bacteria, viruses, fungi and other organisms) have co-evolved with humans over thousands of years and are important to human survival as they have been found to support several vital functions (Cash *et al.,* 2006; Logan *et al.,* 2016; Nagpal *et al.,* 2014; O'Hara & Shanahan, 2006; Rook *et al.,* 2014; Wang *et al.,* 2017). These microorganisms vastly outnumber our human cells by at least an order of magnitude, with most of them residing in our gastrointestinal tract (Gill *et al.,* 2006; Turnbaugh *et al.,* 2007; Zhu *et al.,* 2010).

It is now well established that the microbiota plays an important role in regulating our immune system (Hooper *et al.,* 2012; Rook, 2013; Rook & Knight, 2015; Round & Mazmanian, 2009). It has also been found to contribute to digestion, nutrition (Adams & Gutiérrez, 2018; Bäckhed *et al.,* 2005; Claesson *et al.,* 2012; Filippo *et al.,* 2010; Kau *et al.,* 2011) and defense against pathogenic organisms and to influence a number of metabolic, physiological, immunological processes (Belkaid & Hand, 2014; Candela *et al.,* 2008; Fukuda *et al.,* 2011; Hooper *et al.,* 2003; Lee & Mazmanian, 2010; Macpherson & Harris, 2004; Sommer & Bäckhed, 2013).

Declines in the abundance and diversity of human microbiota often associated with modern lifestyles have given rise to dysbiosis and associated dysbiosis-related diseases (such as inflammatory bowel disease) (Ehlers & Kaufmann, 2010; Ipci *et al.,* 2017; Mosca *et al.,* 2016; Sommer *et al.,* 2017), thereby contributing to the rising global burden of noncommunicable diseases (Liang *et al.,* 2018; Logan *et al.,* 2016). Factors contributing to these altered patterns of the gut microbial ecosystem include industrialization, urbanization, overuse of antibiotics (Bello *et al.,* 2018; Cox & Blaser, 2015; Khanna & Pardi, 2016; Lange *et al.,* 2016; Sekirov *et al.,* 2010; Tanaka *et al.,* 2009; Verhulst *et al.,* 2008) and chemicals (Claus *et al.,* 2016; Velmurugan *et al.,* 2017), dietary changes (Filippo *et al.,* 2010), childbirth and neonatal practices (Bäckhed *et al.,* 2015; Lynch & Pedersen, 2016), and reduced/limited early-life exposure to microbial diversity in the wider environment (Fallani *et al.,* 2010; Huttenhower *et al.,* 2012; MacGillivray & Kollmann, 2014; Mosca *et al.,* 2016; Prescott, 2013). In particular, these changes in microbial exposures are linked with a rise in inflammatory disorders such as asthma (Ver Heul *et al.,* 2019), allergic (Haahtela *et al.,* 2013; Hanski *et al.,* 2012; Rook *et al.,* 2013; von Hertzen *et al.,* 2011), and other autoimmune diseases (such as multiple sclerosis) (Chen *et al.,* 2016); inflammatory bowel diseases (McIlroy *et al.,* 2018; Sartor, 2008), diabetes (Boerner & Sarvetnick, 2011), cardiovascular diseases and obesity (Boulangé *et al.,* 2016; Tang *et al.,* 2017; Turnbaugh *et al.,* 2006), some cancers (Scanlan *et al.,* 2008; Vétizou *et al.,* 2015) and neurological disorders (Parashar & Udayabanu, 2017; Szablewski, 2018), autism (Bjorklund *et al.,* 2016; Finegold *et al.,* 2002; Li & Zhou, 2016) and psychiatric conditions such as depression (Aerts *et al.,* 2018; Evrensel & Ceylan, 2015; Rook *et al.,* 2014; Thomas *et al.,* 2017).

Proximity to natural and farm environments (in particular those in which traditional farming methods are used sustaining rich microbe environments) reduces the incidence of some inflammatory diseases such as asthma (Mosca *et al.,* 2016; Schaub & Vercelli, 2015; Stein *et al.,* 2016). As a result, higher rates of inflammatory disorders found in some modern cities may be associated with reduced microbial exposure (both in the environment and from contact with animals) (Schaub & Vercelli, 2015; Tun *et al.,* 2017).

These and other findings have implications for the development of targeted interventions such as the restoration of microbial diversity, for example, through dietary changes (Adams & Gutiérrez, 2018; Filippo *et al.,* 2010; Riccio & Rossano, 2018; White *et al.,* 2018), sound antibiotic stewardship (Khanna & Pardi, 2016; Tanaka *et al.,* 2009), traditional medicines (Thakur *et al.,* 2014), and restoration of microbial biodiversity in the environment, including soil and urban environments, to improve, physical and mental health (Aerts *et al.,* 2018; Cryan & Dinan, 2012; Liang *et al.,* 2018; Marchesi *et al.,* 2016; Mills *et al.,* 2017; Rieder *et al.,* 2017; Rook *et al.,* 2013; Rook & Knight, 2015).

2018). Visitation to national parks and urban green spaces are indicators of values associated with nature. Countries that normally top most global happiness surveys are associated with very strong conservation ethics. Happiness and psychological well-being are multidimensional however; security, employment, family, friendship are all important.

Medicinal Products: Many antibiotics, cancer fighting drugs, and painkillers such as aspirin are originally derived from nature (e.g., Salicylic acid is found in willows; the genus *Salix*). IPLCs frequently have specific knowledge and use of natural products, which can serve as their primary source of medicine. The perpetual evolutionary battle between predator and prey, parasite and host, including of microscopic biodiversity (bacteria, fungi), is a dynamic source of novel medicines including new antibiotics to battle antimicrobial resistance. While modern medicines are largely synthesized rather than cultivated, the majority of new medicines continue to be sourced from nature (Newman & Cragg, 2012; Schippmann *et al.*, 2006). Metrics for nature's contribution are in the proportion of novel drugs sourced from biodiversity, the economic value of novel drugs, and/or increased DALY's.

2.3.4.3 Economic valuation of NCP

Economists have developed a variety of market and non-market valuation methods applicable to measuring the value of many NCP (Champ *et al.*, 2003; Freeman III *et al.*, 2014; TEEB, 2010; US EPA, 2009), and there are large databases of estimates of value along with relevant references (Carson, 2011; Van der Ploeg & de Groot, 2010). Applications of economic valuation methods generate estimates of value measured in monetary terms. The three main advantages of applying economic valuation methods to measure the impacts on human well-being are that: 1) impacts on well-being are reported in a common (monetary) metric that allows for comparison across different NCP, 2) measures are readily understood by many decision makers in governments and the private sector, and 3) measures are based on a set of well established methods grounded in economic theory. There are also some significant disadvantages, discussed below.

Economic valuation methods can be readily applied to many material NCP that are embodied in goods bought and sold in markets for which prices exist (e.g., agricultural crops, energy, materials). Even some non-material NCP can be evaluated using evidence from market transactions, such as values associated with recreation and tourism for which the expenses related to travel can be used to estimate the benefits (Freeman III *et al.*, 2014). However, many NCP are not traded in markets, particularly regulatory and non-material NCP, and therefore lack a market price that could be used as a signal of value. In some cases where NCP lack market prices, non-market valuation methods can be applied. These methods can be classified into three broad types: a) revealed preference methods, b) stated preference methods, and c) cost-based methods. Revealed preference methods generate estimates of value based on observed behavior on choices people make. For example, showing that houses located near parks or natural areas have higher property values than similar houses not located near parks or natural areas provides evidence on the value that people place on proximity to parks or natural areas (e.g., Mahan *et al.*, 2000; Sander & Polasky, 2009). Stated preference methods generate estimates of value from responses to survey questions. For example, contingent valuation can be used to ask whether respondents are willing to pay for a certain level of provision of an NCP. Cost-based methods use estimates of the costs of replacing an NCP with a human-engineered substitute. For example, clean drinking water can be supplied by ecosystem processes that filter nutrients and pollutants or by a water filtration facility.

Some NCP, especially non-material NCP such as those linked to spiritual and religious life or supporting identities (NCP 17), generate benefits that are difficult, and perhaps inappropriate, to measure in monetary terms using economic methods (Chan *et al.,* 2012; Daniel *et al.,* 2012; de Groot, 2006; de Groot *et al.,* 2002; MA, 2005; Milcu *et al.,* 2013). Few prior studies evaluate the capacity of nature to provide learning and inspiration (NCP 15), psychological experience (NCP 16), and identity (NCP 17) in monetary terms (Cooper *et al.,* 2016; Daniel *et al.,* 2012). The lack of inclusion of measures of the values of the non-material benefits is an important gap in economic measures of the value of NCP. Various authors approach evaluation of the impact of non-material NCP using other value notions, such as relational (Chan *et al.,* 2016), constitutive (James, 2015), sociocultural (Martín-López *et al.,* 2014), or transcendental values (Kenter *et al.,* 2015; Raymond & Kenter, 2016).

For many NCP in many locations, there are no existing studies that estimate the value of the NCP. Although the use of high-quality primary research is preferred, the realities of limited data and limited resources often dictate that benefit transfer is the only feasible option to estimate values. Benefit transfer is based on the use of valuation studies conducted at particular sites or in specific policy contexts to predict values at other unstudied sites or policy contexts (Johnston *et al.*, 2015). Using benefit transfer enables approximations of economic value to be provided when time, funding, or other constraints prevent the use of primary research to generate estimates of value. When considering the use of primary valuation research versus benefit transfer, the central trade-off is between the resources and time required for the analysis and the level of accuracy in estimated values. Benefit transfers can generally be conducted more easily than primary valuation but can involve significant errors when not done carefully.

Some prior estimates of ecosystem service valuation use a particularly simple form of benefit transfer based on applying a value estimate per unit area of habitat type (e.g., Costanza *et al.,* 1997; Troy & Wilson, 2006). This approach assumes that every hectare of a particular habitat type is of equal value to every other hectare of that habitat type and ignores both ecological and social-economic heterogeneity that is often crucial in determining the value of ecosystem services (Plummer, 2009; Polasky & Segerson, 2009). Other critiques point out that it is invalid to simply scale estimates derived at a small spatial by the amount of total area (Bockstael *et al.,* 2000). Because of substantive issues raised in the literature about benefit transfer based on applying a value estimate per unit area of habitat type, we do not use this approach nor report on estimates of the value of ecosystem services that rely on this approach. This rules out many of the most widely cited monetary estimates of ecosystem services.

Critics of applying economic valuation to NCP raise several issues. First, economic valuation methods may unfairly privilege the wealthy over the poor. Economic valuation depends on willingness-to-pay, and willingness-to-pay depends on the distribution of wealth and income. The poor will not be willing-to-pay as much as the rich even for important NCP simply because they lack the ability to pay. Second, there is evidence that framing issues in terms of markets and money can alter how people value nature (Falk & Szech, 2013; Sandel, 2012). Finally, some critics think it is impossible to capture spiritual and religious values using economic valuation, as such values are fundamentally different from economic values (Cooper *et al.,* 2016; Satterfield *et al.,* 2013; Stephenson, 2008).

In Section 2.3.5, we include economic measures of the value of various NCP, particularly for material NCP, but for other NCP as well where available. Though it is important to include other measures of value of NCP in addition to economic measures, economic measures can be influential with government agencies (e.g., ministries of finance) as well as with the private sector.

2.3.4.4 Social, cultural, and holistic measurements of NCP

Identifying social, cultural, or holistic values (including sociocultural, political, historical, patrimonial, and others) of nature by social-cultural groups across the planet requires understanding the diverse ways in which individuals and groups interact with nature and their differing concepts of quality of life. Local understanding and practices about these relationships influence and are influenced by local modes of conceptualizing nature and related practices and knowledge, which may or may not correspond to a discreet measurable entity (Descola, 2013; Ellen & Fukui, 1996). Nature-culture relationships respond to and affect social norms, values and beliefs, social interactions (languages about nature, classifications, symbols and signs), ways of defining law and justice (including rights of access to resources, tenure, heritage and matrimonial systems), and processes that link the material to the non-material, the tangible to the intangible, and myths and taboos (Descola, 2013; Foucault, 1966; Levi-Strauss, 1966). All these interconnected dimensions may be shared within societies and may be transmitted across generations through social learning, but they may also be contested, disrespected, or actively replaced in the face of new pressures and/or culture change. Notions of a good quality of life are linked to values that are generally local, but also, and increasingly due to media and global trade, include values and expectations from the larger society or even completely different regions (Sterling *et al.,* 2017a). For example, the value of local food systems and their diversity as elements representing the identity of a given society is changing very quickly as trade exchanges at the global level increases the global homogeneity of food diversity used and therefore choices made locally (Khoury *et al.,* 2014).

When there are conflicts about an element of nature, approaches and methods to understand values need to consider their distinct social-cultural contexts. For example, extracting and trading wild medicinal plants to urban consumers may conflict with social-cultural, economic, and health values of people living in source areas who may have an emotional and cultural relationship to place and resources as well as those who depend economically or medicinally on these resources (Cunningham, 1993; Enioutina *et al.,* 2017; Hamilton & Aumeeruddy-Thomas, 2013; Richerzhagen, 2010). Non-material benefits cover a wide spectrum and may be intellectual, spiritual, emblematic, or symbolic (see also relational values; Chan *et al.,* 2016). To understand these values, it is important to work in local contexts because cultural, ecological, economic, and social values are intertwined, and priorities may vary greatly in different geographical regions. This puts emphasis on cultural significance rather than cultural values and emphasizes how people establish significant meaning around components of nature.

One of the key indicators for IPLCs refers to 'connection to land' and 'connection to sea' (Cuerrier *et al.,* 2015; see also CBD), which is a holistic indicator that relates to memory of place and its biodiversity, its role for economic needs, and also to adapting to changing environments such as climate change (McMillen *et al.,* 2014). This indicator can be interpreted as whether community members have the possibility and the right to engage with the land and sea directly by cultivating their ancestral land and hunting or harvesting or fishing in these territories and includes their capacity to adapt and transform to face environmental change (Marshall *et al.,* 2012). Additionally, personal and community connections to land (and sea) facilitate co-production of other NCP such as learning from nature through direct learning or transgenerational transmissions, especially important for children (NCP 15) (Dounias & Aumeeruddy-Thomas, 2017; Gallois & Reyes-García, 2018; Simenel, 2017) and inspiration for instance regarding artistic expression or recreational uses (NCP 15, 16) (Balmford *et al.,* 2015; Wolff *et al.,* 2017).

Integrated approaches to understanding significant cultural meaning related to nature using the idea of connectedness and locally-based approaches consider the following: (1) cultural uniqueness, (2) community reliance on nature that links to livelihoods, incomes, and level of importance for well-being; (3) cultural traditions (connectedness to place, rituals, width of interest across the community); (4) dramatic cultural change (the role of the element of nature considered in periods of dramatic change to address identity, or other sources of meaning). In addition, some integrated approaches consider the resilience of the social-ecological system and their ability to recover, adapt, and transform in the face of environmental change (Folke, 2006).

Due to this complexity and depending on the objectives for evaluating sociocultural and holistic values, a diversity of methods is used, with a major common denominator being linking values to places and developing scoring approaches at the local level. Some of the diversity of methods used are shown below although this is not an exhaustive list. Combinations of several methods are often used:

- Qualitative in-depth and open interviews followed by encoding of discourses for analysing preferences
- Developing narratives in general to understand emotions, sense of place, cultural memory, and situated knowledge (Nazarea, 2016)
- Using maps coupled to field related anthropological and sociological approaches, including understanding social behavior and networks related to a specific type of resource and its geography (Reckinger & Régnier, 2017)
- Analyzing social exchange networks in relation to a specific resource such as seed exchange networks (Salpeteur *et al.*, 2017)
- Analyzing world views and conceptualizations of nature and how this links to specific practices, and evaluating nature classifications through anthropological approaches (Sanga & Ortalli, 2003)
- Free listing and ranking approaches (Martin, 1995)

2.3.5 STATUS AND TRENDS OF NCP CO-PRODUCTION AND IMPACT ON GOOD QUALITY OF LIFE

This section presents information on the status and trends of co-production of NCP and on the impact of NCP on good quality of life. The co-production of NCP is an important determinant of the impact of NCP on quality of life, but impact also depends on anthropogenic assets, institutions, governance, culture, and other social, economic, and political factors. Our analyses attempt to disentangle the effects of changes in nature from changes in human factors on the co-production of NCP, and on impacts on good quality of life, by presenting trends in potential NCP, output, and impact of NCP on good quality of life side by side **(Figure 2.3.3)**. Though the results presented in **Figure 2.3.3** are not causal, showing potential NCP, output, and impact helps to illuminate the main factors related to changes in NCP. Changes in potential NCP arise primarily from changes in nature. In contrast, changes in impact on good quality of life can arise from changes in nature, such as a decline in habitat leading to a reduction in the co-production of an NCP, or from changes in anthropogenic factors affecting the way people use and value an NCP. For example, even with no change in co-production, changes in access rules, human-made substitutes, or cultural norms that change how people interact with nature may cause shifts in how an NCP contributes to good quality of life. **Figure 2.3.3** also helps to illuminate differences between NCP and outcomes that people care about, such as the filtration of air and water pollutants (NCP 4 and 7) versus outcomes of primary interest to people (air and water quality). **Figure 2.3.3** does not include realized NCP. Realized NCP is the same as output for material and non-material NCP. For regulating NCP, realized NCP and output generally are different, with output measures more closely aligned to impacts on good quality of life. For example, when air or water emissions increase, ecosystems may filter more pollution (realized NCP increases), but air or water quality may decline (output decreases). We also show the global distribution of selected indicators relevant to NCP **(Figure 2.3.4)**, and the relative status of NCP across terrestrial biomes **(Figure 2.3.5)**.

Methods & indicators

Chapter authors systematically evaluated literature on co-production of NCP, impacts on good quality of life, and the status and trends for each of the 18 NCP presented in **Table 2.3.1**. To accomplish this, chapter authors developed a standardized template and undertook an expert evaluation following guidelines for systematic review (Collaboration for Environmental Evidence, 2013). In the templates, authors summarized the theory of NCP co-production and impact, and also summarized evidence about the status and trends in NCP. From these templates, authors then summarized evidence supporting global trends in co-production of potential NCP, output, and impact, which are presented in **Figure 2.3.3** with explanation in **Table 2.3.4**. The longer templates and supporting data are contained in Supplementary Materials, Appendix 2. Authors also identified and explained global, distributed data proxies to quantify NCP used to assess status and trends in each IPBES unit of analysis. These units of analysis encompass 11 terrestrial and 6 aquatic biomes and anthropogenic systems ranging from tropical forests to aquaculture areas to urban areas. Specific literature review was conducted for IPLCs and ILK for all NCP, and more extensive evaluations of ILK of climate regulation (NCP 4), soil development (NCP 8), and hazard regulation (NCP 9) are incorporated in the chapter and provided in Supplementary Materials, Appendix 1.

To visualize and quantify NCP status and trends, indicators (Niemeijer & de Groot, 2008) for potential NCP, output, and impact on good quality of life were selected for each NCP. Separate indicators for potential NCP, output, and impact on good quality of life were chosen, as trends in each may differ (Hattam *et al.,* 2015). Candidate indicators were identified through review of the literature on each NCP (see Appendix 2). One to two indicators for each NCP were selected by consensus through dialog among chapter authors. Selection criteria prioritized scientific soundness and IPBES policy relevance (de Groot *et al.,* 2010; Heink *et al.,* 2016; Maes *et al.,* 2018). NCP indicators presented in **Figure 2.3.3** align with indicators in prior assessments for NCP that align with categories of ecosystem services used in prior assessments (Hattam *et al.,* 2015; Shepherd *et al.,* 2016; UNEP-WCMC, 2011). **Figure 2.3.4** includes data only for natural terrestrial biomes; NCP from oceans, freshwater, cultivated areas, and urban areas are not included in this figure. However, such areas, along with natural terrestrial biomes, are addressed in the text below.

Global, distributed data to represent potential NCP, outcome, and impact on good quality of life, relies heavily on biophysical data at present. Some global economic values, particularly for material NCP, are available. However, many indicators of NCP are not readily available globally. More data are available at regional and local levels, including qualitative measures that incorporates observations, tallies, perceptions, desires, visions, and experiences of local

Table 2 3 3 **Global Data Proxies Representing Select NCP presented in Figure 2.3.5.**

NCP	Data Proxies	Citation
NCP 3: Air quality regulation	Leaf Area Index	(Zhu *et al.,* 2013)
NCP 4: Climate regulation	Terrestrial Net Primary Productivity	(Zhao *et al.,* 2005)
NCP 6: Water quantity regulation	Evapotranspiration	(Mu *et al.,* 2013)
NCP 7: Water quality regulation	Bare Area	(Klein Goldewijk *et al.,* 2017)
NCP 8: Soil regulation	Soil Organic Carbon	(IPBES, 2018a; Stoorvogel *et al.,* 2017; Van der Esch *et al.,* 2017)
NCP 9: Hazard regulation	Area of Floodplain Wetlands	(Reis *et al.,* 2017)
NCP 11: Energy	Net Primary Productivity in Forests and on Cultivated Land	(ESA, 2017; Zhao *et al.,* 2005)
NCP 12: Food	Cultivated Area	(ESA, 2017)
NCP 13: Materials	Above Ground Biomass in Forests	(ESA, 2017; Liu *et al.,* 2015)
NCP 14: Medicine	Medicinal Species as a Fraction of Total Vascular Plant Species	(Kreft & Jetz, 2007; data S. Pironon and I. Ondo, see RGB Kew, 2016)
NCP 15: Learning	Geographical Overlay of Linguistic Diversity and Biodiversity	(Hammarström *et al.,* 2018; Purvis *et al.,* 2018; Stepp *et al.,* 2004)
NCP 17: Identity	Rate of Land-Use Change	(Klein Goldewijk *et al.,* 2017)

communities (Sterling *et al.,* 2017a). Few of the indicators proposed in previous research directly refer to existing datasets that are both global and spatially explicitly (de Groot *et al.,* 2010; Feld *et al.,* 2009; Hattam *et al.,* 2015; Heink *et al.,* 2016; Maes *et al.,* 2018; Pongratz *et al.,* 2018), but we aligned with these suggested indicators when possible. Average values were calculated for each data proxy over each biome. The indicators used to create **Figure 2.3.5** are summarized in **Table 2.3.3**.

ILK provides a wide range of indicators of nature (see chapter 2.2) and NCP. The ILK indicators most often used for NCP relate directly to co-production, i.e., interactions between people and nature that determine NCP provision. These indicators include population size, spatial distribution, animal behavior, and phenology of economically and/or culturally important wild plant and animal species, such as hunted animals, medicinal herbs, fodder species, and sacred species (Berkes, 2012; Ghimire *et al.,* 2004; Verschuuren *et al.,* 2010). Quantitative measures of plant and animal species are most often abundance values (e.g., number or density of individuals in a certain area; Ticktin *et al.,* 2018). In some cases, especially for economically important NCP, data may exist on harvest or catch per unit effort, or distance travelled to reach a resource (e.g., distance to firewood or water source). Another important group of NCP indicators from ILK describes the quality of an ecosystem that provides essential resources. For example, ILK may describe the quality of rangelands based on the health of the soil or the density of preferred and palatable species (Yacoub, 2018).

IPLCs often use holistic and fuzzy indicators that are not readily quantifiable (Berkes & Berkes, 2009), making them difficult to summarize and include in a global assessment. ILPC perception and categorization of NCP are often considerably different from the 18 NCP categories shown in **Figure 2.3.3** and **Figure 2.3.5**. Some ILPC indicators are similar to NCP categories used in this assessment. For example, the health of the forest (Caillon *et al.,* 2017) is similar to NCP 1 (maintenance of habitat). However, the IPLC indicator of the health of the forest is broader and more inclusive than maintenance of habitat. Biocultural approaches capture both the ecological underpinnings of a cultural system and the cultural perspectives of an ecological state and thus highlight interactions and feedbacks between humans and their environment (Sterling *et al.,* 2017a). Some IPLC indicators of nature monitor supernatural beings like the presence or encounter rates with supernatural forest dwelling entities (Lyver *et al.,* 2018).

2.3.5.1 Global Status and Trends across NCP

Figure 2.3.3 summarizes global trends in potential NCP, output, and impact on good quality of life based upon a comprehensive and systematic literature review. **Table 2.3.4** provides background for **Figure 2.3.3**. Section 2.3.5.2 discusses the ways trends in NCP differ by IPBES unit of analysis. Section 2.3.5.3 provides a summary discussion for each NCP. Longer and more detailed discussion for each NCP are given in Supplementary Materials, Appendix 2. Appendix 1 provides an assessment of NCP from an ILK perspective when conducted separately from the long descriptions in Appendix 2. Section 2.3.5.4 addresses knowledge gaps. Two NCP, habitat creation and maintenance (NCP 1), and maintenance of options (NCP 18), do not have meaningful distinctions between potential NCP, output, and impact of NCP on good quality of life. For these two NCP we report only on trends in potential NCP. For all other NCP (NCP 2 – 17), we report on status and trends for potential NCP, output, and impact on good quality of life.

Globally, the majority of NCP have experienced a decline in potential NCP (left panel of **Figure 2.3.3**), output (central panel of **Figure 2.3.3**), and impact on quality of life (right panel of **Figure 2.3.3**). Land-use change, climate change, and other major drivers of ecosystem change (see chapter 2.1) have caused changes in nature (see chapter 2.2) that have caused declines in many NCP both in terms of co-production and impact on quality of life.

Trends in Potential NCP

Globally, potential NCP has declined for 14 of 18 NCP. Potential NCP has declined for habitat (NCP 1), regulatory NCP with the exception of regulation of ocean acidification (NCP 2-4, 6-10), medicinal, biochemical and genetic resources (NCP 14), non-material NCP (NCP 15-17), and maintenance of options (NCP 18). Over the past 50 years, agricultural expansion, and to a lesser extent expansion in other human dominated land uses (mining, energy, urban, and built areas), have led to increases in both potential NCP and output of material production dependent on agricultural and other transformed lands for energy, food, and materials (NCP 11-13). The expansion of human-dominated land uses has caused a reduction in the area of forests, grasslands, and other natural habitats. The reduction in natural habitat has been the largest single factor contributing to the decline of potential NCP over the past 50 years. Potential NCP has also declined for elements of material NCP that depend on forests or marine stocks (NCP 11-13). For regulation of ocean acidification, a decrease in potential of terrestrial ecosystems to absorb CO_2 driven mostly by land-use conversion has been offset by an increase in potential to absorb CO_2 in marine systems caused by warming of the upper ocean driving an increase in net primary productivity.

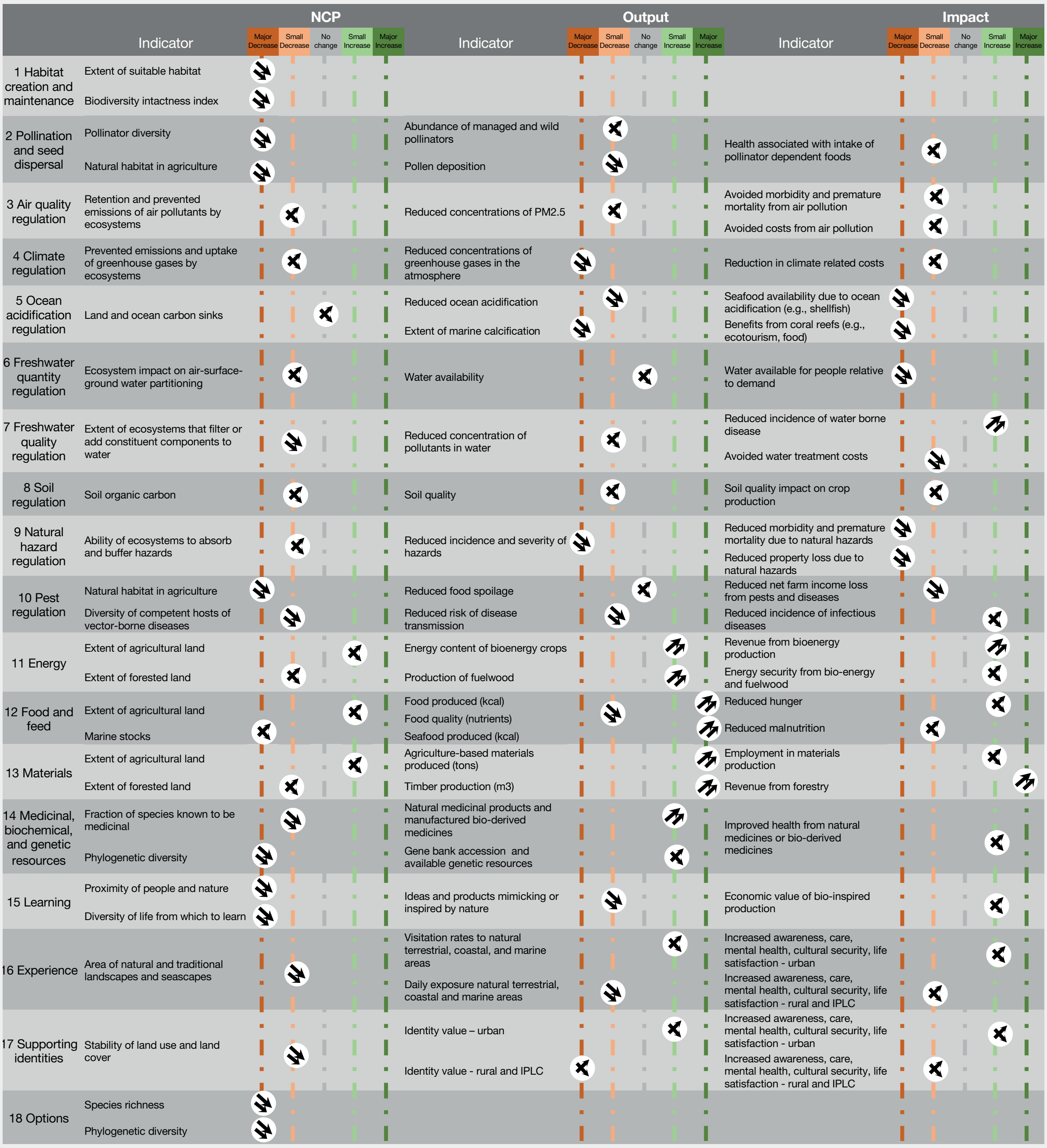

Figure 2 3 3 Global trends in potential NCP, output, and impact on good quality of life by 18 NCP.

For each NCP, the overall global trend over the past 50 years (1968-2018) for potential NCP (left panel), output (center panel), and impact on good quality of life (right panel) is indicated by a symbol and its location in columns indicating either major decrease, small decrease, no change, small increase, or major increase. When comprehensive data do not go back 50 years, trends are for a shorter period of time that match the length of data. Indicators are defined so that an increase in the indicator is associated with an improvement in NCP, output, or impact. Indicators related to harm or damage are thus defined as a reduction in harm or damage. Double arrows pointing either up or down indicate increasing or decreasing trends, respectively, across regions that are similar in direction but differ in magnitude. Crossed arrows indicate that trends in different regions show significant differences (e.g., declines in forests in most tropical regions and increases in forests in many temperate regions). Habitat creation and maintenance (NCP 1) and Maintenance of options (NCP 18) are both defined in terms of contributing to potential NCP and do not relate directly to output or impact on good quality of life.

Table 2 3 4 **Summary Evidence Base for Global Trends over the Past 50 Years by NCP.**

NCP	Potential	Output	Impact
1 – Habitat	Significant global habitat declines (Butchart *et al.,* 2010b) with differing magnitudes across regions. Well established.		
2 - Pollination	Global decrease in pollinator diversity (IPBES, 2016; Potts *et al.,* 2016; Regan *et al.,* 2015), most in industrialized regions, little evidence elsewhere (Bartomeus *et al.,* 2013; Biesmeijer *et al.,* 2006; Cameron *et al.,* 2011; Carvalheiro *et al.,* 2013; Koh *et al.,* 2016). Habitat destruction indicates decreases (Garibaldi *et al.,* 2011; Potts *et al.,* 2016). Well established.	Global decrease in pollinator abundance (IPBES, 2016; Potts *et al.,* 2016); indications of loss in pollination potential (Aizen & Harder, 2009; Garibaldi *et al.,* 2011; Koh *et al.,* 2016). Global deficits in crop pollination (Garibaldi *et al.,* 2016, 2011, 2013). Established but evidence is scattered.	Health impact from declines in animal pollinated-food via micronutrient deficiency (Smith *et al.,* 2015). Nutrition contribution from pollinator-dependent crops varies globally (Chaplin-Kramer *et al.,* 2014). Low income groups have less ability to compensate.
3 – Air Quality	Increase in air pollutants from biomass burning, deforestation, and agriculture, but increase in plant leaf area increases pollution retention and vegetation protects soils and prevents dust (Lelieveld *et al.,* 2015). Unresolved urban impact (Keeler *et al.,* 2019).	Global increase in emissions of fine particulate matter, black carbon, sulfur oxides, and ozone, but major regional variation (OECD, 2016). Well established by distributed monitoring networks.	3.3 million premature deaths annually attributed to air pollution (Amann *et al.,* 2013). Increasing trend in Asia and decreasing in US and Europe (Lelieveld *et al.,* 2015). Increasing cost of healthcare and lost work (OECD, 2016). Mixed impacts across user groups.
4 – Climate	Stable but spatially variable terrestrial sequestration in biomass and emissions from land use change, substantial interannual variation (Keenan *et al.,* 2015; Le Quéré *et al.,* 2018; Song *et al.,* 2018). Would be more sequestration with no anthropogenic land management (Erb *et al.,* 2018). Increase in methane and nitrous oxide emissions (Tian *et al.,* 2016). Precise contributions of ecosystems incomplete.	Greenhouse gas concentrations in the atmosphere have increased dramatically in the last 70 years (IPCC, 2014; Tarasova *et al.,* 2018). Well established.	Increase in economic cost of climate-driven extreme events leading to deaths, proliferation of diseases; agricultural disease outbreaks, and property damage (IPCC, 2014). Some regions have experienced improvement in agricultural production and fisheries (IPCC, 2014).
5 – Ocean Acidification	Stable terrestrial greenhouse gas emissions from land use change and sequestration in biomass (Le Quéré *et al.,* 2018). Increase in ocean carbon sequestration (Le Quéré *et al.,* 2018). Warming of upper ocean increases range of nitrogen-fixing phytoplankton, increasing ocean net primary productivity (Duarte, 2017; Morán *et al.,* 2010).	Ocean acidification has increased (IPCC, 2014) and marine calcification has dramatically declined (Kroeker *et al.,* 2010).	Decline in shellfish availability (Kroeker *et al.,* 2010). Increasing economic damage of coral reef loss, estimated to be US$500 to 870 billion by 2100 (Brander *et al.,* 2012).
6 – Water Quantity	Increased run-off quantity and flow speed due to deforestation, expanding (unirrigated) cropland, and urbanization (Sterling *et al.,* 2013; Trabucco *et al.,* 2008). Ecosystem change impact on water regulation established but incomplete (van Dijk & Keenan, 2007).	Global river discharge constant over past 50 years, but spatially variable (Haddeland *et al.,* 2014; Milliman *et al.,* 2008). Groundwater increases in some regions, decreased in others (Rodell *et al.,* 2018). Well established.	Increasing human water demand globally increasing water scarcity (Brauman *et al.,* 2016; Haddeland *et al.,* 2014). Regional variation but all are affected (WWAP, 2015). Impacts vary depending on adaptation capacity, but all are affected (WWAP, 2015). Direct linkages from water scarcity measures to impacts are inconclusive.
7 – Water Quality	Decreased filtration potential due to increased impervious surfaces and vegetation removal (Mayer *et al.,* 2007; Sweeney & Newbold, 2014), though varies globally (Seto *et al.,* 2012). Mechanisms well-understood but filtration effectiveness varies widely among studies (Mayer *et al.,* 2007; Sweeney & Newbold, 2014).	Global decrease in water quality; nutrient pollution and pathogens increasing and regionally variable trends in industrial waste (UNEP, 2016). Many local studies and some government reporting, but few globally consistent water quality measurements and indicators (UN Water, 2018).	Global decrease in the prevalence of water-borne disease, though at different rates (Prüss *et al.,* 2002; UNEP, 2016). Water-borne disease is well studied (WHO & UNICEF, 2017). Extent, quality, and spending on water treatment and sanitation increasing (WHO & UNICEF, 2017). Extent and expansion of infrastructure is well monitored (WHO & UNICEF, 2017).
8 – Soils	Global decline in soil organic carbon, regional variation (FAO & ITPS, 2015; IPBES, 2018a; Lal, 2015a, 2015b; Pierzynski & Brajendra, 2017).	Global decline in soil quality (FAO & ITPS, 2015; IPBES, 2018a; Lal, 2015a, 2015b; Pierzynski & Brajendra, 2017).	Declining crop yield due to soil degradation; regional variation (Bakker *et al.,* 2007; Lal & Moldenhauer, 1987; Sonneveld *et al.,* 2016). Variable capacity to compensate using substitutes like mineral fertilizer (Blanco-Canqui & Lal, 2008).

Table 2 3 4

NCP	Potential	Output	Impact
9 – Hazards	Decreased natural hazard regulation from land use change including shoreline hardening, floodplain development, and detrimental forest management (Renaud *et al.,* 2013). Most has reduced hazard regulation, but there have been positive changes (Arkema *et al.,* 2017; Renaud *et al.,* 2013). Mechanisms understood but poorly studied *in situ* (Renaud *et al.,* 2013).	Increasing number and magnitude of hazards (Guha-Sapir *et al.,* 2016; van Aalst, 2006). Number and location of disasters varies substantially year to year (Guha-Sapir *et al.,* 2016). Hazard occurrence is well studied (Guha-Sapir *et al.,* 2016).	Increasing number of people and value of impacted property (Guha-Sapir *et al.,* 2016). More impact with less robust institutions and on more vulnerable social groups (Kahn, 2005; United Nations Human Settlements Programme, 2003). Hazard occurrence and impact is well studied, but hazard regulation inconclusive (Guha-Sapir *et al.,* 2016; Renaud *et al.,* 2013).
10 – Pests	Decline of natural pest enemies and competent hosts of vector-borne and zoonotic diseases in all regions, with larger declines in the tropics and sub-tropics(Jones *et al.,* 2008). Decreased natural habitat in agriculture to support pest predators (Letourneau *et al.,* 2009).	Globally, food spoilage and crop loss due to pests has not changed significantly (Oerke, 2006). Risk of disease transmission has increased (Whitmee *et al.,* 2015).	Increased costs from decline in natural pest control (Oerke, 2006). Decrease in vector-borne disease incidence from 1950 to 1980 but increase in the last 30 years and is regionally variable (WHO, 2014). Established but incomplete.
11 – Energy	Increasing extent of agricultural land, though varies regionally (Alexandratos & Bruinsma, 2012). Global decrease in forested area to provide fuelwood, though varies regionally (Keenan *et al.,* 2015; Song *et al.,* 2018).	Increased energy production by biofuel crops (Koh & Ghazoul, 2008) and fuelwood (FAO, 2018a). Slow growth and some decline in traditional biomass, primarily for cooking and heating, with changing technology.	Increasing income from biomass energy (UNDP *et al.,* 2000). Biofuels key to household income (Cavendish, 2000; Dovie, 2003; Paumgarten & Shackleton, 2009; Rajagopal, 2008). Biomass energy, including timber and crop residues, provides energy security to more than two billion people (Schiermeier *et al.,* 2008).
12 – Food	Increase in harvested area, yields, and meat and milk production with regional variation (Alexandratos & Bruinsma, 2012). Decrease in fish catch potential (Cheung *et al.,* 2010), through variable across regions (Srinivasan *et al.,* 2010).	Increasing global production of food (Alexandratos & Bruinsma, 2012). Increased global fish catch and cultured (farmed) fish production (FAO, 2016). Current food production largely meets global caloric needs but fails to provide dietary diversity, notably fruits, nuts, and vegetables, for a healthy diet (Global Panel on Agriculture and Food Systems for Nutrition, 2016).	Decrease in hunger since 1970, though small increasing trend in past decade (FAO *et al.,* 2017). Malnutrition has increased since 1970, driven by increasing obesity, countered in many regions by decreasing undernutrition (FAO *et al.,* 2017).
13 – Materials	Increasing extent of agricultural land, though varies regionally (Alexandratos & Bruinsma, 2012), though area of cotton was stable. Global decline in forest area; much spatial variation (Keenan *et al.,* 2015; Song *et al.,* 2018).	Production of a majority of material resources has increased globally, though there is considerable diversity among materials (FAO, 2018b). Increased timber production (FAO, 2018a).	Globally, employment in forestry has probably increased since 1970 and reported employment has remained stable over the past 20 years (FAO, 2018b; Whiteman *et al.,* 2015). Increasing revenue from forestry (FAO, 2014).
14 – Medicine	Declining fraction of known medicinal species due to ILK decline, including access to customary territories; reduces capacity to identify new drugs from nature (Richerzhagen, 2010). Declining measures of phylogenetic diversity (Faith *et al.,* 2018).	Increase in medicines based on natural products (Newman & Cragg, 2012; Newman *et al.,* 2003). 30,000 new compounds from oceans (Alves *et al.,* 2018). Gene bank accession and genetic resources have increased (Tanksley & McCouch, 1997).	Increased health attributable to nature-based medicines; more than 50% of global population relies almost exclusively on natural medicines (Leaman, 2015; WHO, 2013).
15 – Learning	Declining population living in direct proximity to nature due to urbanization and migration (UN, 2014; WHO, 2016a). Reduced human-nature interactions (Soga & Gaston, 2016). Declining diversity of life from which to learn, measured as phylogenetic diversity (Faith *et al.,* 2018).	Global decrease in biodiversity in conjunction with fewer people living in proximity to nature leads to fewer ideas and products mimicking or inspired by nature (e.g., images of nature in children's media: Prévot-Julliard *et al.,* 2015; Williams *et al.,* 2012).	The overall value of bio-inspired goods is increasing, although it is concentrated within few very large industries (Richerzhagen, 2011).
16 - Experience	Declining area of natural and traditional landscapes and seascapes due to urbanization and land-use change (Seto *et al.,* 2011; Seto & Shepherd, 2009).	Nature visitation rates have risen in some areas and fallen in others (Balmford *et al.,* 2009, 2015). Daily exposure to nature has decreased as urbanization has increased (Soga & Gaston, 2016; Vining *et al.,* 2008).	Wealthy, urban interest in nature has increased (Keeler *et al.,* 2019), but rural migration and land use change have decreased well-being from nature exposure (Claval, 2005), particularly for the poor (United Nations Human Settlements Programme, 2003). Indications of positive mental and physical health impacts from exposure to nature, but findings are inconclusive (Bowler *et al.,* 2010; Daniel *et al.,* 2012).

Table 2 3 4

NCP	Potential	Output	Impact
17 – Identity	Stable human environments provide culture with the possibility to attribute value to it and form identities (Daniel *et al.,* 2012; Plieninger *et al.,* 2015a; Stephenson, 2008). Increased globalization, urbanization, and environmental degradation had decreased stability of land use and land cover (Milcu *et al.,* 2013; Plieninger *et al.,* 2015b).	In urban areas, increasing consciousness of nature and its contributions (Wood *et al.,* 2013). For rural and ILPC, decreasing local resource-based economies and loss of traditional knowledge and lifestyle and thus identities (Kaltenborn, 1998; Pascua *et al.,* 2017). Evidence of these connections is scattered.	Increasing youth interest in nature's contribution to identity (King & Church, 2013), and nature has become engrained in some national cultural identities, livelihoods, and national economies (Daniel *et al.,* 2012). Rural migration and land use change decrease identity linked to nature (Bell *et al.,* 2010; Claval, 2005; Daniel *et al.,* 2012).
18 - Options	Increasing species extinction rates; major regional variation (Ceballos *et al.,* 2017; Pimm *et al.,* 2014). Decreasing phylogenetic diversity (Faith *et al.,* 2018). Trends based on data but the places and species for high diversity loss are not well established.		

Trends in Outputs

The overall global trend in output has declined for 9 of 16 NCP. Output for all regulatory NCP (NCP 2-10), with the exception of water quantity (NCP 6), show a decline in output. As water cycles through the earth system, its volume remains relatively unchanged (NCP 6), although in some cases it has been redistributed, leading to regional variation. The decline in output for many regulatory NCP is related to the decline in potential NCP. For example, the decline in pollination by wild pollinators follows the decline in habitat for wild pollinators. However, for some regulatory NCP, increases in anthropogenic pollution emissions is the main cause of the decline in environmental quality (air quality – NCP 3, climate – NCP 4, and water quality – NCP 7). The atmospheric concentration of CO_2 – the major greenhouse gas – increased by 30% in the last 70 years (IPCC, 2014), driven by increased emissions. Much of the increase in GHG emissions from burning of fossil fuels has come from middle and high income countries, which is the dominant source of GHG emissions, while emissions from land-use change and reduced sequestration has come primarily from low income countries (IPCC, 2014; Pan *et al.,* 2011).

The production of material goods (energy - NCP 11, food and feed - NCP 12, and materials - NCP13) is increasing globally. The increase in production has come mostly from large-scale commercial enterprises. Global timber production has increased 48% relative to 1970 levels (FAO, 2018a). Some of the increases in material goods production, however, may not be sustainable. Overfishing has led to declines in many fish stocks because harvest has exceeded population replacement rates (Jackson *et al.,* 2001; Worm *et al.,* 2006). While fish harvests have increased over the past 50 years, many fish stocks have declined, which puts future fish harvests at risk. A similar pattern holds for medicinal, biochemical, and genetic resources (NCP 14), where the output of drugs, chemical compounds, and agro-seed industry, based on natural resources or mimicking the latter are increasing (Newman & Cragg, 2012), while phylogenetic and intra-specific diversity are decreasing, thus limiting options for the future (NCP 18).

Non-material NCP trends are varied and different indicators of non-material NCP show different trends. For example, there has been an increase in visitation to natural areas, suggesting an increase in experience of nature (NCP 16). However, more people live further removed from nature as the percentage of population living in dense urban areas continues to rise suggests that, for many, the experience of nature is declining. In contrast to material NCP, for which there are regularly reported global figures that summarize important trends in output, there is little agreement on what are the most appropriate measures of output, or regularly collected data with which to summarize global trends of non-material NCP.

Trends in Impact of NCP on Good Quality of Life

The overall global trend of impact of NCP on quality of life declined for 7 of 16 NCP, shows a mixed pattern for 6 NCP, and an unambiguous increase for 3 NCP. Changes in the impact of NCP on quality of life arise from changes in the co-production of NCP as well as from changes in factors more closely related to changes in institutions and anthropogenic assets, availability of substitutes, and human preferences. Increases in anthropogenic assets and human-made substitutes have offset the declines in potential NCP for some categories of NCP. For example, improvement in public health and sanitation measures have tended to reduce incidence of vector-borne diseases (NCP 10) even as potential NCP to regulate such diseases has declined.

The overall trends on impact on good quality of life across NCP are less negative than are the trends in potential NCP, in large part because of the interplay between changes in co-production and changes in social, economic, and political factors. The global trend for impact on good quality of life from material NCP (NCP 11-14) is positive, with the exception of reductions in malnutrition, from both under-nutrition and obesity (NCP 12). Nutrition problems do not arise from lack of ability to produce food. There has been a trend of rising calories per capita over the past 50 years (Alexandratos & Bruinsma, 2012; FAO, 2017b). Increasing agricultural production is largely due to increasing yields resulting from the use of modern varieties, increasing application of fertilizers and other inputs, as well as from expansion of the area in crop production (Alexandratos & Bruinsma, 2012; Foley *et al.*, 2011). With the global increase in food production, impact on malnutrition shows that the number of stunted children has decreased from 165.2 million in 2012 to 150.8 million in 2017, a 9 per cent decline (FAO *et al.*, 2018). Simultaneously, however, the prevalence of anemia among women of reproductive age, which has significant health and development consequences for both women and their children, has risen incrementally from 30.3 per cent in 2012 to 32.8 per cent in 2016, with no region showing a decline (FAO *et al.*, 2018)**.** Further, the unequal distribution of food means that there are over 800 million people suffering from hunger and malnutrition (FAO *et al.*, 2017), along with other nutrition problems arising from poor diets (Global Panel on Agriculture and Food Systems for Nutrition, 2016).

The overall trend for impact on good quality of life from regulatory NCP (NCP 2 – 10) is negative, with the exception of one indicator of water quality (NCP 7) and one indicator for pest regulation (NCP 10). These largely negative changes in the impact of NCP on good quality of life from regulatory NCP have been largely driven by declines in the co-production of NCP. For NCP 7, increased expenditure on water treatment has provided a substitute for decreases in water quality and the capacity of ecosystems to filter water, though poor water quality continues to have negative impacts on good quality of life.

Trade-offs among NCP

The pattern of increasing material NCP and declining regulatory NCP is largely a result of human management of ecosystems across the globe (MA, 2005; Rodríguez *et al.,* 2006; TEEB, 2010). NCP tend to come in bundles that depend on human actions such as land-use decisions and come with trade-off among different NCP (Raudsepp-Hearne *et al.,* 2010a; Rodríguez *et al.,* 2006). For example, land intensively managed for agriculture produces large amounts of energy (biofuels), food, or materials, but often at the cost of reducing natural vegetation and habitat for native species, carbon sequestration and storage, water quality, and other regulatory NCP (Bennett *et al.,* 2009; Polasky *et al.,* 2008; Smith *et al.,* 2012). Land-use and land management choices that are good for habitat preservation and biodiversity also tend to be good for many regulatory NCP (Chan *et al.,* 2006; Nelson *et al.,* 2009; Polasky *et al.,* 2012). However, even among synergistic NCP, there will rarely be perfect alignment. As a result, targeting for the provision of one NCP will typically mean that other NCP will not achieve their maximum potential outcome (Lawler *et al.,* 2014; Polasky *et al.,* 2012). Understanding the consequences of alternative land-use and land-management decisions, investing strategically in ecosystem restoration, and allocating land based on its contribution to multiple NCP, can generate simultaneous increases in the provision of multiple NCP (Bateman *et al.,* 2013; Lawler *et al.,* 2014; Ouyang *et al.,* 2016; Polasky *et al.,* 2008).

Decisions made in one location at one time can have impacts across many regions both now and into the future (Rodríguez *et al.,* 2006). Through international trade in commodities, there is virtual trade in carbon and water (e.g., Dalin *et al.,* 2012; Davis *et al.,* 2010; Hanasaki *et al.,* 2010; Liu *et al.,* 2017; MacDonald *et al.,* 2015; Peters *et al.,* 2012, 2011; Sato, 2014). Globalization and trade from distant demand can increase pressure on local ecosystems and on co-production of NCP (Chi *et al.,* 2017; Wolff *et al.,* 2017). Direct environmental linkages can also cause impacts across geographic regions and over time, as when there important impacts downwind (air quality regulation, NCP 3) or downstream (water quantity regulation, NCP 6, and water quality regulation, NCP 7), or through loss of habitat for migratory species (NCP 1).

2.3.5.2 Status by unit of analysis

For the vast majority of NCP, trends over the past 50 years in potential NCP, realized NCP, output, and impacts on good quality of life show significant differences by unit of analysis. In many cases, illustrated by crossing arrows in **Figure 2.3.3**, outputs move in different directions. For example, air quality, as measured by concentrations of PM2.5, has generally improved in high income countries over the past 50 years while it has declined, often significantly, in low and middle income countries over the past 50 year. For other NCP, trends are either downward or upward but differ significantly in magnitude, illustrated in **Figure 2.3.3** by two arrows in the same direction but with different length. For example, agricultural production has been generally increasing across the globe, but the extent of the increase varies widely across regions. In some cases, global greenhouse gas concentrations (NCP 4) and ocean acidification (NCP 5), effects are global and show similar patterns across units of analysis. NCP with strong consistent trends across biomes include air quality regulation (NCP 3), which is increasing as LAI increases globally (Zhu *et al.,* 2016), and soil (NCP 8), which has universally degraded from a pristine state (IPBES, 2018a; Stoorvogel *et al.,* 2017; Van der Esch *et al.,* 2017). Landscape cultivation for agriculture has occurred across all biomes **(Figure 2.3.4c)**, with the most agricultural land in temperate grassland and Mediterranean forest, followed by tropical forest, then temperate forest and grassland. Thus, as illustrated in **Figure 2.3.5**, potential for food production (NCP 12) is highest in temperate grassland. This is directly responsible for a decrease in potential for NCP that are more strongly related to intact habitat, such as habitat (NCP 1), options (NCP 18), pollination (NCP 2), pest regulation (NCP 10), and water quality regulation (NCP 7), which are lowest in the biomes in which agriculture is highest **(Figure 2.3.5)**. Because there is little conversion to agriculture in tundra, and to some extent drylands, these biomes have the lowest potential to produce food but the most potential to produce habitat-reliant NCP. Though food is both cultivated and wild-collected, we use cultivated area as a global indicator in **Figure 2.3.5** because the majority of global caloric production is cultivated.

Non-material NCP do not lend themselves to quantitative measures that can be assessed globally in the same way as regulating and material NCP. For Identity (NCP 17),

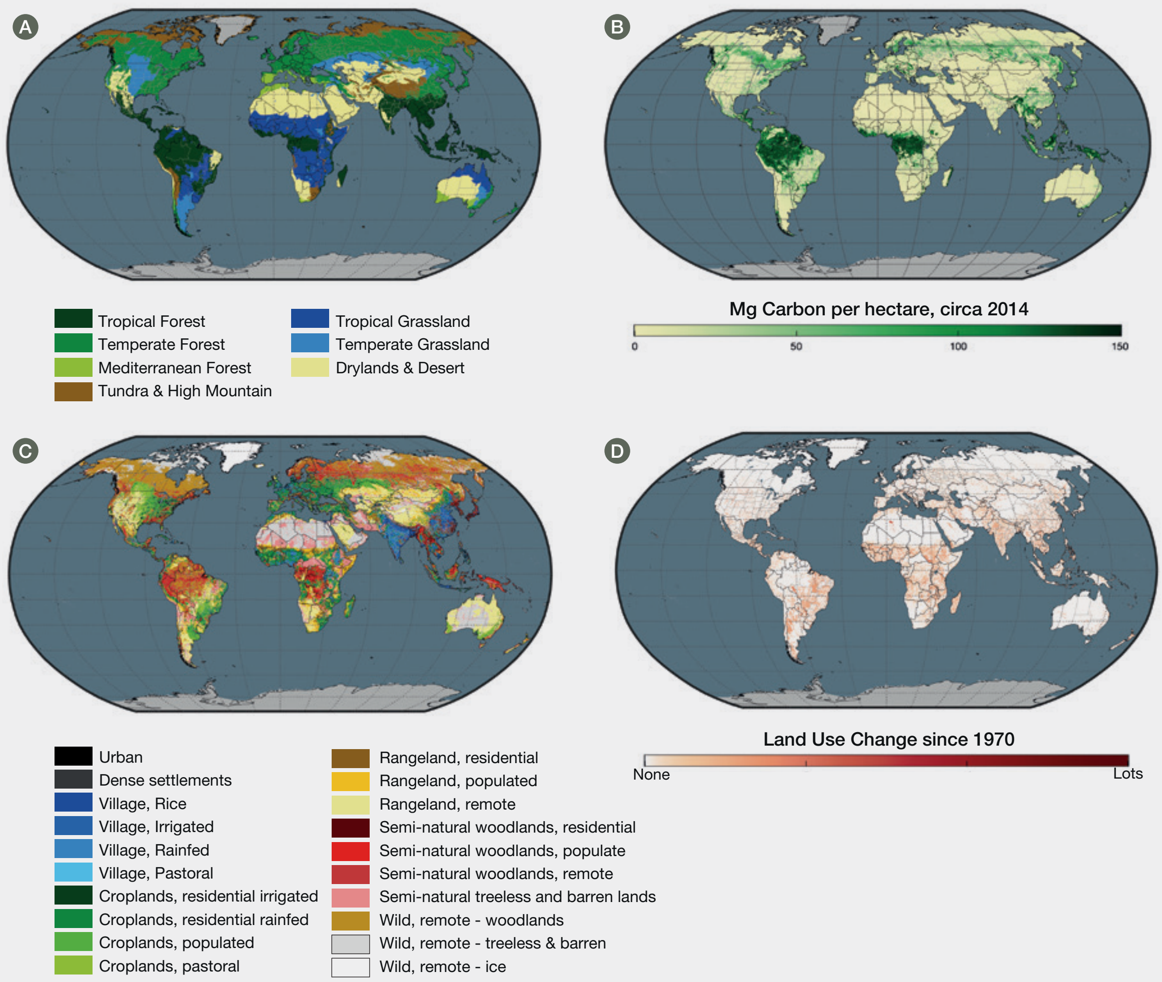

Figure 2 3 4 **Global Distribution of Selected Indicators Relevant to NCP.**

Across terrestrial biomes globally A, status and trends of NCP differ, yet some NCP co-vary. For example, biotic productivity is important for regulation of air (NCP 3), climate (NCP 4), and water quantity (NCP 6) and provision of energy (NCP 11) and materials (NCP 13); one indicator of biotic productivity is above ground biomass B. NCP that rely on relatively intact ecosystems, such as habitat (NCP 1), pollination (NCP 2), regulation of pests (NCP 10), and maintenance of options (NCP 18) have better status in places with more semi-natural and wild landcover C. Global land uses D. Land-use change since 1970 (high rates of land-use change was used as proxy for declining non-material NCP 17).

recognizing that abrupt changes in land use negatively affects identity (Antrop, 2005; Palang *et al.,* 2011), we use historic land use change since 1970 as an indicator **(Figure 2.3.4)**. Using a data proxy, we see that changes in tropical forest and grassland mean these biomes provide lower levels of identity NCP **(Figure 2.3.5)**. In many places, land use change was more dramatic between 1920 and 1970 than from 1970 to the present (Klein Goldewijk *et al.,*

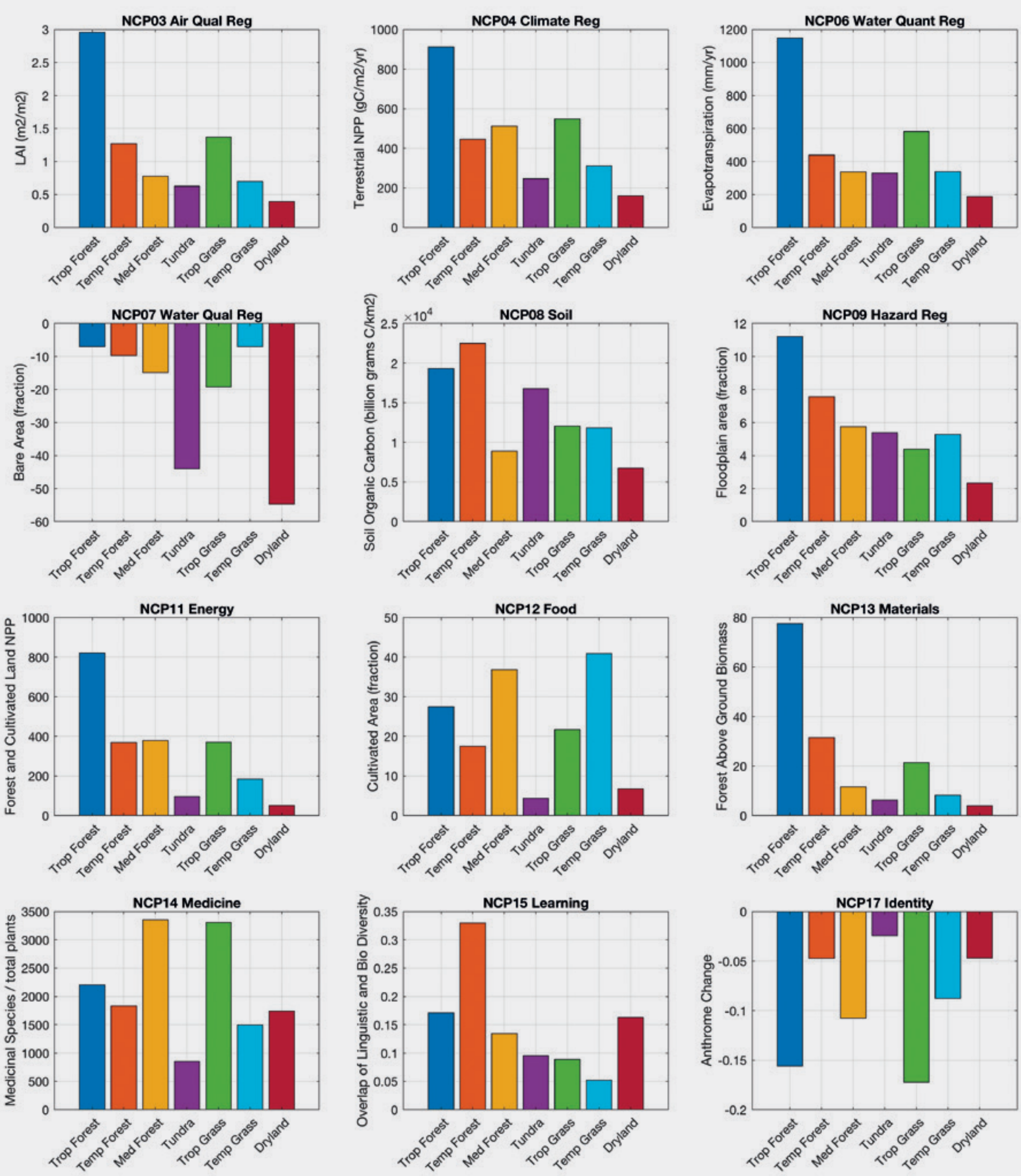

Figure 2 3 5 **Global Distribution of Data Proxies Relevant to Selected Potential NCP.**

NCP Status across biomes calculated using data proxies of the potential NCP indicators from **Figure 2.3.5**. Data were identified based on literature referenced in appendices and selected based on availability and alignment with subsection nature and other IPBES assessments. Few of the indicators proposed in previous research directly refer to existing datasets that are both global and spatially explicitly (de Groot *et al.*, 2010; Feld *et al.*, 2009; Hattam *et al.*, 2015; Heink *et al.*, 2016; Maes *et al.*, 2018; Pongratz *et al.*, 2018), but we aligned with these suggestions when possible. Average values were calculated for each data proxy over each biome. Data sources are listed in **Table 2.3.3**.

2017). For identity (NCP 17), the data proxy tells us there is plausibly a positive trend because potential NCP is less negative than it was in the preceding time period. Though current indicators and data proxies are weak, the help to recognize and track experience of nature in many all environments and over specific time periods.

Biotic productivity is a central component of many NCP. Both energy (NCP 11) and materials (NCP 13) are produced on agricultural lands, but fuelwood and timber make up a substantial fraction of total stocks, so we based indicators on biotic productivity. Similarly, air quality regulation (NCP 3), indicated by leaf surface area, climate regulation (NCP 3), indicated by net carbon sequestration, and water quantity regulation (NCP 6), indicated by transfer of water to the atmosphere, are very high in tropical forests, very low in tundra and drylands, and moderate in temperate and Mediterranean forest and grasslands **(Figure 2.3.5)**. Increasing biotic productivity means that, for most biomes, indicators of climate regulation (NCP 4), materials (NCP 13), and energy (NCP 11) are increasing. However, conversion of tropical forest **(Figure 2.3.4b, d, Figure 2.3.5)** counteracts this, leading to decreasing regulation of climate (NCP 4) and provision of energy (NCP 11) there.

Tropical forest, despite deforestation and downward trends for many NCP, continues to be incredibly important in providing for people. For most NCP, tropical forest is the biome with the highest potential for many NCP, including energy (NCP 11) and materials (NCP 13), as well as regulating services such as air (NCP 3), climate (NCP 4), and water distribution (NCP 6). Mediterranean forest and temperate grassland have the largest relative area converted to cultivated land, so while they are critical providers of food and feed (NCP 12), they provide lower levels of other NCP, particularly those linked to habitat intactness. Tropical grasslands have also been converted for food production, but because of their high biotic productivity **(Figure 2.3.4b)**, like tropical forests they continue to provide relatively high levels of NCP related to biotic production. By contrast, tundra and drylands have naturally lower levels of biotic productivity **(Figure 2.3.4b)** and so provide low levels of productivity-linked NCP, but as a result they have also had substantially less conversion for food production and so have relatively high levels of NCP provided by intact habitat. Co-production of medicine (NCP 14) is indicated by the fraction of vascular plants known to be medicinal, reflecting both biotic presence and human understanding; this is highest in Mediterranean forest and tropical grasslands.

The ocean provides many NCP, notably in meeting food (NCP 12) demand. Global annual per capita consumption of fish has more than doubled since 1960 (FAO, 2016), amounting to an annual increase of 3.2% in fish production for human consumption (UN, 2017). This increase has largely come from aquaculture, which has offset a decline in potential food production from marine fisheries: there was an 11% decline in biomass of assessed fish stocks in the wild between 1977 and 2009 (Worm *et al.,* 2009). Into the future, declines in wild-caught fish landings between 6 and 30% are predicted, depending on region, due to climate change (Cheung *et al.,* 2013). Other key provisioning NCP from oceans are materials (NCP 13) and medicines (NCP 14), both of which have been increasing over the past 50 years. The extraction of materials such as pearls, corals, marine ornamental organisms (pet trade), and shells has increased, particularly due to demand related to increased population and increased aquaria. In the case of marine-sourced medicines (NCP 14), 30,000 new marine medical compounds have been sourced from previously lesser known marine organisms in the last 50 years (Alves *et al.,* 2018). Innovative technologies in the fields of discovery and development of marine-based drugs hold much promise for a future increasing trend in NCP 14 (Montaser & Luesch, 2011).

Oceans also play a critical role in regulating ocean acidification through sequestration of carbon (NCP 5), regulating climate (NCP 4) and regulating natural hazards (NCP 9). For hazards, there has been a 13% decline in coastal protection since 1980, with serious consequences for damage by storms events and other natural disasters, which are increasing in frequency with climate change. In particular, destruction of mangrove forests through coastal degradation, and coral reefs through global warming and ocean acidification, is decreasing coastal protection, both due to reduction as a barrier to storm damage and also because carbon sequestration is declining (Heckbert *et al.*, 2012). For ocean acidification and climate, ocean net primary production, which has increased by around 6% globally between 1998 and 2007 (Behrenfeld *et al.*, 2006; Le Quéré *et al.*, 2018), is helping to mitigate the effects of global warming and ocean acidification through the uptake of CO_2 by marine primary producers. However, the detrimental effects of ocean acidification are reflected in shellfish availability, which has declined under ocean acidification as a result of the uptake of atmospheric CO_2 (Kroeker *et al.*, 2010).

The extensive three-dimensional nature of the oceans and their interactions with land and atmosphere alike (Hattam *et al.*, 2015) results in large spatial variability and uncertainties in the magnitude and even the directions of changes in NCP. However, what is clear is that maintaining healthy and diverse ocean ecosystems will be essential to sustain contributions of marine nature to people.

Freshwater systems get substantial attention for their contribution to food (NCP 12); freshwater fisheries are estimated to provide 40% of global fish production and be a particularly critical food and income resource for low income and subsistence fishers (Lynch *et al.,* 2016).

Within freshwater systems, water quantity regulation (NCP 6) occurs largely through the effects of vegetation on flow speed (Montakhab *et al.,* 2012) and on channel structure, which can in turn affect flow speed (Corenblit *et al.,* 2011). Freshwater systems are also critical for regulating water quality (NCP 7), as they account for about 20% of total global denitrification (Seitzinger *et al.,* 2006). Overall, in-stream processing has probably increased because nutrient loading has increased (Mulholland *et al.,* 2008). Freshwater systems are a net contributor to carbon emissions (Raymond *et al.,* 2013; Webb *et al.,* 2018). Freshwater systems also provide materials (NCP 13) such as mussels, historically used for buttons, and are key to learning (NCP 15), experience (NCP 16) and culture and identity (NCP 17) for many (Lynch *et al.,* 2016). However, freshwater biodiversity is declining rapidly and dramatically, suggesting that provision of many NCP from freshwater systems are declining and will continue to do so (Loh *et al.,* 2005).

Urban areas also provide many NCP, with green spaces such as parks, street trees, and riverbanks providing both regulating and non-material NCP, and a growing body of literature evaluates and assesses these NCP (Elmqvist *et al.,* 2013; Haase *et al.,* 2014; Hartig & Kahn Jr, 2016; Keeler *et al.,* 2019; Luederitz *et al.,* 2015). Trade-offs among NCP in urban areas are often strong: urban trees, for example, provide cooling (NCP 4) (Zardo *et al.,* 2017), stormwater control (NCP 6) (Berland *et al.,* 2017), and may improve mental health (NCP 16) (Keeler *et al.,* 2019), but also require substantial water resources (NCP 6) (Pataki *et al.,* 2011) and may be net contributors to air pollution (NCP 3) through volatile organic compounds and pollen (Janhäll, 2015). Though contact with nature may be decreasing overall, in urban areas there is an increasing demand for parks and green areas that are seen by many as supporting the identity of the town and its people (NCP 17), although there are many debates about the unequal access to green areas or parks by urban dwellers depending on wealth (Tang, 2017; Willemse, 2018). A global study on visitation of green areas and recreation parks shows that the highest demand for outdoor recreation in both rural and urban areas can be found in Canada, USA, Scandinavia, Spain, France, the Netherlands and Switzerland, given high levels of per-capita GDP and thus possibilities to participate in outdoor recreation (Wolff *et al.,* 2017). For water quality (NCP 7), for which increased urbanization and bare ground decrease provision, there is a decreasing trend.

Agricultural areas exhibit the diverse role of human interventions across regulating, material, and non-material NCP. Agroforestry management in the tropics, for example, can simultaneously maintain high levels of biodiversity while providing materials (NCP13), medicines (NCP 14), and learning processes for children (NCP 15) in addition to food production (NCP 12). IPLCs' practices of fresh water management (NCP 7) are illustrated in oases (Battesti, 2005), irrigated rice fields (Conklin, 1980; Settele, 1998), and cultivation on mounds in flooded inundated tropical savannas (McKey *et al.,* 2016, 2014). Contributions of generations of IPLCs to the selection, nurturing, and diversification of local animal landraces and plant varieties is widely recognized (Bellon *et al.,* 2017; FAO, 2007; Jarvis *et al.,* 2011), as is the design of non-industrial agroecosystems. Homegardens and agroforestry systems across the globe contribute to conservation and use of agricultural biodiversity. Diverse examples of IPLC contribution to the management and conservation of genetic resources include Soudano-Sahelian savannas and the large diversity of African cereals (Naino Jika *et al.,* 2017), taro horticulture in the pacific (Caillon *et al.,* 2006), and wild yam management by Pygmee hunter gatherers (Dounias, 1993). These practices are essential for not only the production of food and other directly consumed NCP, but also to maintain future options for the planet (NCP 18).

2.3.5.3 Status and Trends of Each NCP

NCP 1: Habitat Creation and Maintenance

Habitat continues to be in significant decline globally (chapter 2.2; Butchart *et al.,* 2010a). The extent of protected and intact habitat globally provides a critical indictor of NCP1. Many indicators of change in habitat quantity and quality exist, and these have been the subject of numerous reviews (e.g., Geijzendorffer *et al.,* 2016). Change in habitat quantity is best measured as the change in the extent of suitable habitat (ESH); measures of habitat quality in contrast benefit from including some measure of species composition. Recent evaluations have used the Biodiversity Intactness Index (BII) as a surrogate measure (Scholes & Biggs, 2005). ESH measures the extent of suitable habitat relative to a reference year whereas BII indicates the compositional intactness of local communities in comparison to an undisturbed state. It is unclear how much habitat creation and maintenance is required to provide NCP. Some have proposed habitat conservation targets of 50% (Dinerstein *et al.,* 2017; Hudson *et al.,* 2017; Wilson, 2016); 90% (ranging between 30–90%) has been proposed for BII (Steffen *et al.,* 2015). ESH and BII in combination speak to status and trends of habitat quantity and quality. In combination, these indicators suggest that only four biomes are above conservation thresholds: tundra, boreal forests/taiga, tropical and subtropical moist broadleaf forests, and mangroves (Hudson *et al.,* 2017). In contrast, Mediterranean habitats, temperate grasslands, and flooded grassland and savannas are well below either target and continue to decline. Chapter 2.2 discuses status and trends in nature in more detail. Many biomes, particularly those at high latitude, are under increasing threat and loss due to climate change and land use change. Mid-latitude biomes have experienced the greatest degree of habitat loss but are also where the greatest agricultural abandonment may be permitting some habitat restoration (Ramankutty *et al.,* 2008).

NCP 2: Pollination and Dispersal of Seeds

An extensive global review was recently performed by more than 77 scientists for the IPBES thematic assessment on pollinators, pollination, and food production (IPBES, 2016; Potts *et al.,* 2016). Declines in pollinator diversity have been recorded and are expected to continue globally. Currently, 16.5% of vertebrate pollinators are threatened with global extinction (IPBES, 2016; Potts *et al.,* 2016), and declines in bee diversity over the last century have been recorded in industrialized regions of the world, particularly northwestern Europe and eastern North America (Bartomeus *et al.,* 2013; Biesmeijer *et al.,* 2006; Cameron *et al.,* 2011; Carvalheiro *et al.,* 2013; Koh *et al.,* 2016). Evidence on the drivers of pollinator loss suggests a decline in pollinator diversity in Latin America, Africa, and Asia (Garibaldi *et al.,* 2011; IPBES, 2016). Propagule dispersal is also in decline globally. Currently, 26% of vertebrate seed dispersers are globally threatened (Aslan *et al.,* 2013). Species diversity reflects the potential of nature to provide pollination and dispersal services (Garibaldi *et al.,* 2013), while the abundance of organisms (both managed and wild) is used here as an indirect measure of the output (as well as pollen deposition). Usually, sites with more species diversity have also greater abundance (Garibaldi *et al.,* 2013).

These declines in animal pollinators could have significant negative consequences for the level and stability of pollination of crop and wild plants, and therefore good quality of life (IPBES, 2016; Potts *et al.,* 2016). Nearly 90% of wild flowering plant species depend, at least in part, on the transfer of pollen by animals. These wild plants critically contribute to most NCP. Moreover, the production of more than three quarters of the leading types of global food crops rely to some extent on animal pollination. An estimated 5–8% of global crop production would be lost without pollination services, representing US$235–577 billion annually on the basis of 2009 market prices and production (and inflated to 2015 US$) (IPBES, 2016; Potts *et al.,* 2016). Furthermore, changes in human diets and a disproportionate expansion of agricultural land are taking place to fill this shortfall in crop production by volume (Aizen *et al.,* 2009). Important global health burdens from both non-communicable diseases and micronutrient deficiencies are thus also expected due to pollinator loss (Smith *et al.,* 2015). Health impacts can be greater in areas with micronutrient deficiencies, such as Southeast Asia, where 50% of the production of plant-derived sources of vitamin A requires biotic pollination (Chaplin-Kramer *et al.,* 2014). However, these can be partially compensated by human choices of food and agricultural management. User groups vary greatly in their capacity to compensate the loss of pollinator-dependent food with other nutritious foods. Low income groups have less ability to compensate. It is unclear the degree to which humans can compensate for the loss of pollinator diversity.

NCP 3: Regulation of Air Quality

Air quality has declined globally as emissions of fine particulate matter, black carbon, nitrogen and sulfur oxides, and ozone have increased (OECD, 2016). Overall, increases in air pollution are higher in Asia, but reductions in air pollution have occurred in previously industrial regions of America and Europe. Globally, asthma and allergies resulting from air pollution have increased as well (Kim *et al.,* 2013). Nature contributes to regulation of air quality emissions by sequestering these emissions; it is well established that deforestation, biomass burning, and intensive agriculture release air pollutants (Lelieveld *et al.,* 2015). It is also well established that vegetation has the potential to prevent emissions by protecting soils to avoid air dust emissions and trapping some air pollutants in plant parts. There is also potential for nature to retain air pollutants on leafy surfaces, though the extent of this is probably small (Keeler *et al.,* 2019). Conversely, both flora and fauna frequently emit allergens, though more biodiverse species seem to reduce allergy intensity (Cariñanos & Casares-Porcel, 2011; Cresti & Linskens, 2000; Janhäll, 2015). Many of these functions are provided by well-developed vegetation structure, so nature's contribution to retaining and preventing emissions of air pollutants has been compromised through burning, deforestation, and agriculture (Lelieveld *et al.,* 2015). However, at a global level, leaf area has increased (Zhu *et al.,* 2013), so air quality regulation may be increasing. Assessment of air quality regulation by nature has usually been undertaken locally or nationally and has mostly been done in developed countries. Example findings of health benefits from air pollution retention by urban trees were $227.2 million Canadian dollars and $3.8 billion US dollars (Nowak *et al.,* 2006, 2018). In England, one study estimated net pollution absorption by woodlands reduced the deaths related to air pollution by 5–7% and hospital admissions by 4-6%, resulting is costs savings of £17,000–£900,000 (Powe & Willis, 2004).

NCP 4: Regulation of Climate

Atmospheric concentrations of CO_2 have increased by 30% in the last 70 years to levels unprecedented in the modern era, and other greenhouse gases have also increased (IPCC, 2014; WMO, 2017). This has large and negative consequences for humanity (IPCC, 2018). Ecosystems are both a sink and source of CO_2 and other greenhouse gasses (Le Quéré *et al.,* 2018). On land, ecosystems sequester carbon in vegetation and soils, and though there is substantial year-to-year variation, over the last 50 years terrestrial carbon sequestration has probably increased a small amount (Le Quéré *et al.,* 2018). In the oceans, biotic and abiotic processes sequester carbon, and this has also increased (Le Quéré *et al.,* 2018). Land-use change, especially deforestation, burning, and conversion to agriculture, is a major source of CO_2 emissions, nearly offsetting land-based sequestration (Le Quéré *et al.,* 2018). The world's forests are a major sink of CO_2 (Pan *et al.,* 2011), and nature's contribution to climate regulation decreases as forests are cut down and also used intensively (Erb *et al.,* 2018). These changes are not uniformly distributed across the global – global tree cover increased 7.2% from 1982–2016 (Song *et al.,* 2018), but the area of tropical forests – the terrestrial ecosystems with the largest carbon stocks – has declined (Keenan *et al.,* 2015; Song *et al.,* 2018). Overall, the contribution of tropical forests to the global carbon cycle has been, however, nearly neutral (Mitchard, 2018).

ILK is instrumental in maintaining sustainable environments and practices that contribute to climate regulation and its impact on good quality of life through (i) natural resources management, (ii) physical infrastructure, (iii) livelihood strategies, and (iv) social institutions. Reducing the pace and extent of land use change is one way that IPLCs contribute to maintaining nature's regulation of climate. The lifestyle and practices of IPLCs contribute to maintaining significant portions of ecologically intact landscapes globally. Indigenous lands, for instance, represent over a quarter of the world's land surface, including overlaping with near 40% of all terrestrial protected areas (see chapter 1 and 2.2; Garnett *et al.*, 2018). In addition, ILPC practices enhance climate regulation in many landscapes. Agroforestry as practiced by rural communities in South America (~3.2 million 3.2 million km^2), sub-Saharan Africa (1.9 million km^2), and Southeast Asia (1.3 million km^2), for example, maintains complex associations of carbon-storing plants and soils (Zomer *et al.*, 2009).

NCP 5: Regulation of Ocean Acidification

The ocean has the capacity to absorb CO_2 and thereby mitigate ocean acidification. In marine ecosystems, marshes, mangroves, and seagrass meadows take up CO_2 from seawater; carbon stored in these coastal environments is termed "blue carbon" which is locked into organic matter that can be preserved for a long time and may help offset ocean acidification locally. The ocean's regulation of acidification also includes assimilation of CO_2 by phytoplankton, as well as the capacity of seaweed aquaculture to affect pH and provide refugia for marine organisms with shells comprised of calcium carbonate (these organisms are termed calcifiers and include corals, crustaceans and several molluscs). Dense seaweed beds and kelp forests represent productivity hotspots with associated high pH when photosynthesis reduces CO_2 concentrations (Duarte, 2017). They may play a role in protecting calcifiers from projected ocean acidification. With warming of the upper ocean, the geographical range of nitrogen-fixing phytoplankton is likely to expand, so that net primary productivity may increase (although the phytoplankton community may be comprised of a larger proportion of small-celled phytoplankton) (Duarte, 2017; Morán *et al.,* 2010). Ocean acidification is especially problematic for corals and shellfish, because it prevents them from properly developing their skeletons and shells. Shell fish availability has declined under ocean acidification as a result of the uptake of atmospheric CO_2 (Kroeker *et al.,* 2010). Further, tropical coral reef ecosystems provide food, income, and coastal protection for around 500 million people throughout tropical coastal zones. The annual economic damage of ocean-acidification-induced coral reef loss by 2100 has been estimated to be US$500 to 870 billion depending on the level of CO_2 emissions scenarios (Brander *et al.,* 2012), and the corresponding global economic loss of shellfish production due to ocean acidification is estimated to be US$6-10 billion US$ per year (Narita *et al.,* 2012).

NCP 6: Regulation of Freshwater Quantity, Location, and Timing

Freshwater is critical for human well-being, and it is a limited resource distributed unevenly across the globe by natural and human-driven processes. Human demand for water is increasing worldwide, so water scarcity is increasing even when water availability does not change (Brauman *et al.,* 2016; Haddeland *et al.,* 2014). These impacts are unevenly distributed across social and user groups (WWAP, 2015). Nearly 75% of irrigated area and 50% of the population globally are sited in places where more than 75% of renewable water resources are consumed annually, seasonally, or in dry years (Brauman *et al.,* 2016). Changes in water availability are largely a result of changes in climate, evapotranspiration, and in human water extraction and river regulation (Milliman *et al.,* 2008). Ecosystems regulate freshwater by transferring water from the soil to the atmosphere, interacting directly with the atmosphere through processes such as cloud water interception and shading, developing flow paths from the ground surface through the soil, and physically interrupting the flow of surface water (Brauman *et al.,* 2007). The impact of land cover on water regulation occurs local and regionally through changes in evapotranspiration as well as locally via impacts on run-off (Beck *et al.,* 2013; Van Dijk *et al.,* 2009). In total, river discharge globally has remained constant over the past 50 years, though in about one third of rivers discharge has changed by more than 30% (Milliman *et al.,* 2008). Trends in groundwater vary significantly by region, with groundwater increases in areas of deforestation and cropland expansion (Rodell *et al.,* 2018). Global trends in deforestation, replacement of perennial vegetation with annual (un-irrigated) cropland, and urbanization have likely increased run-off quantity and also flow speed (Sterling *et al.,* 2013; Trabucco *et al.,* 2008). Modelling studies have been unable to unambiguously attribute large-scale measured changes in run-off and evapotranspiration to vegetation change (Haddeland *et al.,* 2014; Ukkola & Prentice, 2013).

NCP 7: Regulation of Freshwater Quality

Poor water quality is a critical source of illness in people, irrigation with saline water is a global threat to agricultural productivity, clean water is necessary for many types of manufacturing, and cultural and recreational enjoyment of water bodies is tightly linked to water quality (Prüss *et al.,* 2002). Though access to clean water is increasing and water-borne disease is decreasing, these trends are uneven across user groups (Ezzati *et al.,* 2002; WHO & UNICEF, 2017). Globally, water quality has decreased, though some regions show improved water quality (UNEP, 2016). Nutrient loading from anthropogenic sources, particularly agriculture and wastewater, has increased dramatically over the past 50 years, leading to increased eutrophication (Smith *et al.,* 2003; UNEP, 2016). Industrial water pollution has decreased in some regions but increased in others (UNEP, 2016). Nature can both contribute to and remove constituents in water. Ecosystems may provide direct additions of material to water, and through processing, uptake, and sequestration, they can also remove particles, pathogens, nutrients, and chemicals from water (Brauman *et al.,* 2007). Whether a change in water quality is considered beneficial depends on the suite of desired uses of water (Bernhardt, 2013; Keeler *et al.,* 2012). For example, mussels remove suspended solids, bacterial, and phytoplankton from the water column, which is frequently interpreted as a benefit, but invasive zebra mussels in North America do so to the extent that waters become very clear and cannot support fish or other aquatic life (Macisaac, 1996). The effectiveness of natural pollutant removal, such as through vegetated strips adjacent to waterways or in or wetlands, varies tremendously (Mayer *et al.,* 2007; Sweeney & Newbold, 2014).

NCP 8: Formation, Protection, and Decontamination of Soils

Soil degradation, particularly degradation caused by erosion, reduces crop productivity (Panagos *et al.,* 2018; Scherr, 2000), and the consequences are severe for low and middle income user groups who cannot compensate with anthropogenic substitutes (Blanco-Canqui & Lal, 2008). Land degradation has reduced agricultural productivity on 23% of global terrestrial area and affects 3.2 billion people (IPBES, 2018a). Nature contributes to better soil quality through improvement in soil biodiversity, mainly by enhancing soil organic carbon (SOC), which is a strong determinant of soil quality, soil health and crop productivity. SOC plays a crucial role in soil formation, soil protection, and other soil functions and derived benefits (FAO, 2017a; FAO & ITPS, 2015; Gaiser & Stahr, 2013). Globally, poor soil management practices have led to declines in soil carbon, biodiversity, and nutrients and to an increase in soil erosion, compaction, contamination, sealing, crusting and desertification, resulting in soil degradation and poor soil quality (FAO & ITPS, 2015; IPBES, 2018a; Lal, 2015a). The world has lost an estimated 8% of soil carbon globally due to land degradation, mostly because of agriculture (IPBES, 2018a; Sanderman *et al.,* 2017; Van der Esch *et al.,* 2017). These trends are not uniform globally, however; soil carbon stocks have improved in North America, for example, where widespread adoption of conservation agriculture (e.g., reduced tillage and improved residue management) has improved soil organic carbon stores on some cropland (FAO & ITPS, 2015; Lal, 2015b; Pierzynski & Brajendra, 2017). Despite discrepancies in country and regional estimates of soil organic carbon stocks (Hartemink *et al.,* 2010; Hengl *et al.,* 2017; Köchy *et al.,* 2015; Sanchez *et al.,* 2009), FAO (2017c) suggests that more than 60% of the 680 billion tonnes of carbon is found in ten countries: Russia, Canada, USA, China, Brazil, Indonesia, Australia, Argentina, Kazakhstan and Democratic Republic of Congo.

NCP 9: Regulation of Hazards and Extreme Events

Hazards, including fires, inland and coastal floods, and landslides, are increasing in both incidence and impact over time (Guha-Sapir *et al.,* 2016). While the number of disasters and people affected varies substantially year to year, close to 350 major disasters affecting close to 600 million people were reported in 2016, and the overall trend has been increasing over time (Guha-Sapir *et al.,* 2016). Changing drivers, including the risks of climate change and locations where people live, are increasing both the incidence and impacts of disasters (van Aalst, 2006). Hazards have a greater impact on more vulnerable social groups, and lower income countries and those with less robust institutions tend to be more affected by disasters (Kahn, 2005; United Nations Human Settlements Programme, 2003). Natural systems have the potential to reduce the incidence or impact of fire, floods, landslides, waves, and other destructive natural hazards. Nature and nature-based features can both increase and reduce disaster risk by increasing, preventing, or buffering the impacts of hazards and by changing people's exposure to hazards (Renaud *et al.,* 2013). For fires, floods, landslides, and coastal hazards, the physical structure of vegetation can serve a protective role by physically blocking hazards such as waves or rockfall, roots can help secure soils and sediments, stabilizing the abiotic elements of an ecosystem, and areas dedicated to natural ecosystems may physically displace people and structures that would be damaged by natural hazards. Ecosystems also help reduce hazards and their impacts by dissipating energy, moving water, and regulating fuel for fires. Nature-based approaches to disaster risk reduction are becoming increasingly appealing, but conversion of landscapes including shoreline hardening, floodplain development, and detrimental forest management that increases hazard impact remains widespread (Arkema *et al.,* 2017).

ILK enables some ILPC not only to anticipate, manage, and respond to natural hazards such as tsunamis (Lauer, 2012), cyclones (Paul & Routray, 2013), and heavy rains (Roncoli *et al.,* 2002). In many cases, responses to hazards reflect the magnitude of the perturbation. Papua New Guineans, for example, shift their farming practices in response to short-term frosts but engage in long-distance migration in response to long-term ones (Jacka, 2015). In addition, knowledge of wild or semi-domesticated plants provides survival foods in times of resource shortage (Yates & Anderson-Berry, 2004) (see Supplementary Materials, Appendix 1). The long-term transfer of knowledge, experiences, and practices related to disasters provides resilience to many IPLCs, though this is eroding in many areas experiencing cultural, inter-generational, and economic changes.

NCP 10: Regulation of Organisms Detrimental to Humans

Natural regulation of pests and pathogens improves food security, economic security, and human health. Weeds, animal pests, pathogens and viruses reduce production of food and cash crops worldwide. The absolute value of crop losses and overall proportion of crop losses have been steady over the past 40 years, fluctuating between 20–30% depending on crop and region (Oerke, 2006). Globally, chemical controls such as herbicides and pesticides have increased by 15–20% (Oerke, 2006), often substituting or replacing pest and disease regulating NCP co-produced by diversified cropping systems (within-field or alpha diversity) or cropping landscapes (between-field or beta diversity) (Tscharntke *et al.,* 2016). Vector-borne diseases infect more than 1 billion people per year, accounting for more than 17% of all infectious diseases, with more than 1 million deaths recorded from vector-borne diseases including malaria, dengue, schistosomiasis, leishmaniasis, Chagas disease, yellow fever, lymphatic filariasis and onchocerciasis (Karesh *et al.,* 2012). Trends in disease incidence are variable, with some diseases on the decline (malaria mortality -40% globally) but many more increasing (dengue +30-fold increase, Lyme disease currently the most common tick-borne disease globally) (Jones *et al.,* 2008; WHO, 2014). Climate change poses risks for crops and human disease, as habitat and infection ranges of crop pests (Bebber, 2013) and disease vectors (Kilpatrick & Randolph, 2012) expand. Loss of biodiversity could either increase or decrease disease transmission, though mounting evidence suggests that biodiversity loss increases disease transmission (Keesing *et al.,* 2010). Overall, despite many remaining questions, current evidence indicates that preserving intact ecosystems and their endemic biodiversity should generally reduce the prevalence of infectious diseases (Keesing *et al.,* 2010).

NCP 11: Energy

Bioenergy is renewable energy made from materials derived from biological sources. Biomass feedstocks are organic material that has stored energy from sunlight in the form of chemical energy and include plants, residues from agriculture or forestry, and the organic components of municipal and industrial wastes (Dale *et al.,* 2016). More than 2 billion people rely on wood fuel to meet their primary energy needs (Schiermeier *et al.,* 2008), and harvest and sale of biofuels often make up a a substantial portion of household income (Angelsen *et al.,* 2014). Use of biofuels, including biofuel crops (Koh & Ghazoul, 2008) and fuelwood (FAO, 2018b), is growing rapidly around the world. About 90% of bioenergy is consumed for traditional use – fires for household heating and cooking, but in recent years biomass has become a source of electricity, liquid fuel, and heat for towns and cities. It has been estimated that the world's generating capacity from biomass is at least 40 GW per year as of 2000 (UNDP *et al.,* 2000), and the extent of agricultural land on which bioenergy is produced is increasing (Alexandratos & Bruinsma, 2012).

NCP 12: Food and Feed

Globally, production of food is high and increasing, though the magnitude of these trends varies around the world. For agricultural crops, both harvested area and yields have increased, and meat and milk production have both increased over the past 50 years (Alexandratos & Bruinsma, 2012), yet meat and milk production have increased ten and sevenfold in Asia, while only 81% and 8% in Europe. Global fish catches increased by around 50% over the last 50 years, and cultured (farmed) fish production escalated from insignificant fractions of wild catch to comprise ~40% of total seafood production in 2015 (FAO, 2016). In the last ten years, wild fish catch declined by 10% whereas farmed fish/seafood increased by 20% (FAO, 2016; Worm *et al.,* 2009). Fish catch potential is expected to vary in both magnitude and direction depending on temperature, oxygen and pH changes, which are projected to be different in different parts of the globe (Cheung *et al.,* 2016).

Despite these increases in production, the potential of nature to sustainably contribute to food production is declining. Land degradation has reduced agricultural productivity on 23% of global terrestrial area and affects 3.2 billion people (IPBES, 2018a). All taxa of wild crop relatives have decreased, with an estimated 16–22% of species predicted to go extinct and most species losing over 50% of their range size (Jarvis *et al.*, 2008). Similarly, fish catch potential, a measure of fisheries productivity as a function of primary production and distribution of fish and invertebrates (Cheung *et al.*, 2010), is variable across areas but has decreased substantially, with 7–36% loss in catches estimated for 2000 due to overfishing (Srinivasan *et al.*, 2010), and there is little scope for expanding fisheries into the future (FAO, 2016).

The impact of these trends in output as well as potential NCP on quality of life is variable. While current food production could largely meet global caloric needs, unequal distribution of calorie uptake among regions, high levels of food waste, and intensive production of a limited number of crops in large quantities (cereals, starchy root crops, meat and dairy, oilseeds, and sugar) mean that malnutrition remains prevalent. Hunger has decreased globally since 1970, though there are still over 800 million people facing chronic food deprivation and those numbers have increased slightly in the past decade (FAO *et al.,* 2017, 2018). The prevalence of undernourishment is highest and worsening in many regions of Africa, affecting almost 21% of the population (more than 256 million people); The prevalence of undernourishment is estimated to be 5% in South America and 11% in Asia (FAO *et al.,* 2017, 2018). Malnutrition has increased since 1970, driven by increasing obesity, countered in many regions by decreasing undernutrition (FAO *et al.,* 2017, 2018). National food supplies worldwide are now more similar in composition than previously, leading to the establishment of a global standard food supply, which is relatively species-rich in regard to measured crops at the national level, but species-poor globally (Herrero *et al.,* 2017; Khoury *et al.,* 2014). Dietary diversity, notably in fruits, nuts, and vegetables, required in a low health risk diet (Global Panel on Agriculture and Food Systems for Nutrition, 2016; Johns *et al.,* 2013; Powell *et al.,* 2015). Food production systems that integrate more diversity and less chemical inputs such as agroforestry systems could improve diversified diets and reduce impacts on climate, soil, water quality, and habitat (Springmann *et al.,* 2018). For fishers, demand for fish resources is increasing, likely with reduced benefits in terms of livelihood per fisher (McCluskey & Lewison, 2008; Worm *et al.,* 2009).

NCP 13: Materials and Assistance

The production of a majority of material resources has increased globally since 1970, though there is considerable diversity among them. The production of materials extracted from forest ecosystems such as timber (round wood production), natural gums, and resins has increased since 1970 (FAO, 2018a). Likewise, production has increased of a majority of fibre crops derived from agroecosystems such as cotton, agave, coir, and silk; production of some other fibers has decreased (hemp, sisal, bastfibres) or remained relatively constant (jute, manila) (FAO, 2018a). Although cotton growing area has remained constant, cotton production has nearly doubled since 1961 due to improved seed varieties, irrigation, and the use of pesticides and herbicides (Cotton Australia, 2016). For many materials, the trend in recent decades has been towards more heavily managed systems. For example, timber is increasingly harvested from forest plantations, traded wildlife such as birds, reptiles, and aquarium fish are increasingly produced in captivity, and most of the traded ornamental plants, including orchids, are now produced in cultivated systems. Trends in provision of different material resources vary around the world. Forest plantations have increased in boreal regions, Central America, South America, and South and Southeast Asia (Keenan *et al.*, 2015). Collection of materials can decrease the potential for provision over the long term. For example, one cause of coral reef degradation is extraction for aquarium use (Jackson *et al.*, 2001).

Materials impact quality life by providing shelter, providing raw materials for many industries such as textiles, furniture, and crafts, are sources of inspiration, and create employment and provide income. Globally, total employment in the forestry sector was about 13.2 million in 2011, a decline of about six per cent from 2000 (FAO, 2014). Trends in forestry employment vary across regions. Western and Eastern Europe, North America, and the developed Asia Pacific region have seen major declines in forestry sector jobs, due in part to the global economic crisis in 2008–2009, replacement of manual work with machinery (Europe, Australia, New Zealand), increasing import of furniture from the other regions (North America), and decreasing production (Japan) (FAO, 2014). Other regions, however, have increased forestry employment. Developing Asia-Pacific, Latin America and the Caribbean, North Africa, and Western and Central Asia combined created 1.1 million new jobs between 2000 and 2011 (FAO, 2014). This increase occurred mainly in China, India, Vietnam, and Thailand as wood processing and pulp and paper industries expanded rapidly, primarily for export. Employment in the global textile industries, including cotton cultivation, is increasing.

NCP 14: Medicinal, Biochemical, and Genetic Resources

Materials derived from organisms (plants, animals, fungi, microbes) for medicinal and veterinary purposes contribute to health, income, and cultural development, medical systems being a set of culture associated with a range of relational values (MA, 2005). These products represent full organisms, portions of organisms, and genetic resources including genetic information (Richerzhagen, 2010). Identifying natural products and transforming them into Natural Medicinal Products (NMPs) depends both on human capacity to identify species and link them to specific illnesses and the availability and quality of these species.

Box 2 3 2 **Caterpillar Fungus, an example of NCP 13 Materials.**

Known popularly as 'Himalayan Viagra,' the caterpillar fungus *(Ophiocordyceps sinensis)* is the world's most expensive biological commodity (Shrestha and Bawa, 2013). Used in traditional Chinese medicine and recently embraced as an aphrodisiac and a powerful tonic to enhance libido, the caterpillar fungus is found only in high-elevation pastures in the Himalayas and Tibetan plateau. It is an endo-parasitic complex formed when the pathogenic fungus parasitizes the caterpillars of ghost moths (Hepialidae) found above 3500m. The tiny 2-6-inch-long fruiting bodies, each weighing less than a half gram, are harvested by hundreds of thousands of mountain dwellers in China, India, Nepal, and Bhutan every year from May to July (Shrestha and Bawa, 2013).

Harvest and sale of the caterpillar fungus supports poverty-stricken local people, accounting for more than 70% of many people's total income (Shrestha and Bawa 2014). However, though the fungus has brought economic prosperity to regions where livelihood options are limited, its harvest has created social and environmental problems. Unsustainable over-harvest and climate change have reduced the number of caterpillar fungus collected each year, leading to conflict between communities over resource rights (Hopping *et al.,* 2018). Increased collection effort has sent more people further afield, degrading grassland habitats. In response, collection and trade of caterpillar fungus has been banned in India and regulated in Nepal and Bhutan yet harvest and trade into the multi-billion dollar international market as continued unabated. Photo: Uttam Babu Shrestha.

Tens of thousands of medicinal plants are used (Hamilton, 2004; Leaman, 2015; Schippmann *et al.,* 2006). Globally, more than 25% of new drugs are derived from natural products, with more than 70% of drugs to treat cancers derived directly from natural medicinal products (Newman & Cragg, 2012; Newman *et al.,* 2003). More than 20% of modern drugs used for all diseases globally are based on leads from natural molecules, identified by science or based on ILK; these include aspirin, vincristine, and taxol. The search for new medicines has concentrated in plants; 70,000 medicinal plants species, about 17% of the world known flora, are estimated to be used at the global level (Schippmann *et al.,* 2006 - IUCN Medicinal Plants Specialist Group). There are 656 flowering plant species used to treat diabetes (Allkin *et al.,* 2017), which affects an estimated 422 million adults. In addition, terrestrial animals, fungi and ocean biodiversity have potential to provide medicinal resources, but few taxa have been tested or explored thoroughly (Colwell, 2002). Over the last 50 years, more than 30,000 new compounds and more than 300 patents have been derived from marine species (Alves *et al.,* 2018). Similar patterns are known for fungi, based on existing Asiatic pharmacopeia, which has been little studied to date. Certain taxa have proven to be more likely to have useful compounds. ILK or scientific screening approaches use taxonomic cues and concentrate their efforts in specific biota to identify natural medicinal products (Saslis-Lagoudakis *et al.,* 2014, 2012).

Though discovery and use of new drugs and compounds based on nature has increased (Newman & Cragg, 2012; Newman *et al.*, 2003), this is largely due to advances in techniques over the last 30 years as well as major discoveries in new areas of investigation such as marine products or fungi (Alves *et al.*, 2018; Newman & Cragg, 2012). Declines in biodiversity mean we are losing genetic resources, with consequent loss in the potential for new discovery of drugs and biochemical compounds (Richerzhagen, 2010). It is estimated that 21% of known medicinal plants are threatened (Schippmann *et al.*, 2006). Loss of knowledge, especially traditional orally-transmitted pharmacopeia, also threaten the potential to identify new medicines (Aswani *et al.*, 2018). The intersection of global plant richness (Kreft & Jetz, 2007) with known plant medicinal species (RGB Kew, 2016) is an indicator showing areas with differential potential across units of analysis and ecosystems.

The impact of natural medicinal resources on quality of life includes direct impacts on health as well as income generated by traditional medicine production and the pharmaceutical industry. It is estimated that 70–80% of people worldwide rely chiefly on traditional, largely herbal medicine to meet their primary healthcare needs (Farnsworth & Soejarto, 1991; Hamilton, 2004). In 2003, the WHO estimated the annual global market for herbal medicines to be worth US$60 billion, and by 2012 the global industry in Traditional Chinese Medicine alone was reported to be worth US$83 billion (Allkin *et al.,* 2017). In 2006, the pharmaceutical market comprised US$ 640 billion, with 25–50% of the products derived from genetic resources; it is estimated that the pharmaceutical industry earns about US$32 billion a year in profits from products derived from traditional remedies (Richerzhagen, 2010, 2011). The agricultural seed market's value was US$30 billion in 2006, and all of its products are derived from genetic resources from nature (ten Brink *et al.,* 2011).

NCP 15: Learning and Inspiration

Proximity to nature enhances learning processes, and the richness of nature is the basis of learning processes including subsistence, science, art, and ensuring humanity's basic and non-material needs (material protection, food, health, communication, culture, religion etc.) (Descola, 2013; Ellen, 2002; Kuo *et al.,* 2019). Direct sensorial experiences with nature are critical to learning and ensuring psychological health (Cox *et al.,* 2017; Dounias & Aumeeruddy-Thomas, 2017). An indicator of nature's importance to learning is shown by the correlation between high cultural diversity and areas of high biodiversity (IPBES, 2018a; Maffi, 2002; Stepp *et al.,* 2004). Mimicry of nature is the origin of many scientific findings: chemical dyes and colors (Nieto-Galan, 2007), bio-inspired medicines (Newman & Cragg, 2012), and sustainable bio-materials (Hunter, 2017). Patterns in nature also inspire thinking processes, such as phylogenetic trees (Hinchliff *et al.,* 2015). Across all cultures, nature is symbolized within paintings, engravings, sculptures, theatre, dancing, language, and other forms of artistic or cultural expression (Cohen, 2005; Fernández-Giménez, 2015; Hunter, 2017).

Learning from nature is declining due to both overall loss of species richness, evidenced by loss of ethnoecological knowledge of nature, and changes in lifestyles (Aswani *et al.,* 2018). Urbanization decreases proximity with nature and tends to change the forms of relationships between people and nature. More than 50% of the global population now lives in urban areas, far from relatively natural areas or biodiversity rich landscapes. Lack of proximity to nature decreases knowledge, especially ILK critical to identification of natural medicinal products. Learning processes are likely to decrease with a global decrease in ILK (Aswani *et al.,* 2018), and global capacity to learn from ILK is therefore likely to decrease. Declines in nature-based learning may be particularly acute in agrodiversity and medicine, where traditional selection of crops and identification of natural medicines have derived initially from ILK. Learning about food-related genetic resources, of which the vast majority are found in traditional agroecosystems such as shifting cultivation, is declining as industrial monocultural plantations increase (Heinimann *et al.,* 2017). There is a significant loss of representation of nature in art and an increase in fragmented use of nature in science that is often disconnected from natural processes. Declines in nature-based learning are not universal, however; some sub-populations increase learning by travelling to natural areas for recreation (Wolff *et al.,* 2017) and by accessing nature through books, television, and the Internet. The digital age is likely to facilitate new connections between nature and culture (Ithurbide & Rivron, 2017; Liang, 2009).

Humankind learns from nature, experiments and learns from natural processes, and uses ecological traits to select crops, medicines for healing, and produce materials. Learning to modify nature for the benefit of humankind is one of the major principles of learning. This type of learning is the basis of humankind's capacity to transform natural processes and thereby replace many of the benefits of nature, such as the development of chemicals to replace soil fertility. This kind of transformative learning also allows people to change the composition of nature through genetic modification. As a result, science is increasingly using information from nature and then mimicking nature, for example using abstract equations or fractals to access elements of nature or using nanotechnologies to develop biomimicry (Hunter, 2017), leading to a slight decrease in the use of nature

Box 2 3 3 **Learning and Experiences: Why proximity to nature matters to our children .**

Nature matters to children. Natural environments provide developmental benefits for children and promote creativity, exploration, divergent thinking that can aid recovery from stress (Wells & Evans, 2003; cited by Sargisson & McLean, 2012), and cognitive restoration. Children report a desire for more trees and green spaces in their schools (Sargisson & McLean, 2012). Throughout the world and in all societies, children are known to observe nature differently than adults (Dounias & Aumeeruddy-Thomas, 2017), to access spaces in nature that adults do not use, such as climbing on trees, and to do this even in landscapes where very little nature remains. Children establish analogies between human worlds and non-human worlds by creating special linkages with nature through their imagination (Simenel, 2017). Children's access to nature can follow very different rules in different societies; this was observed in Indonesian agroforestry systems where private agroforests can only be accessed by their owners yet children from all village families are allowed to transgress such rules, given them special access to wild fruits of different kinds never eaten by adults (Aumeeruddy-Thomas, 1994).

Children give particular attention to some taxa for which adults do not care. As shown by Simenel *et al.* (2017):

"Playing with insects is probably a constant and almost universal element in the history of human childhoods. The universal character of the recreational appeal of insects for children lies in two of their characteristics: first, the diversity of their forms and behaviors, however bizarre they may at first appear to young humans, never fail to stimulate their imaginations, and second, their small size is the basis on which many cultures draw analogies to the small size of children. Costa Neto (2003) notes in his work in Brazil that most children in rural areas play with insects. Similarly, whilst it is adults who indulge in cricket fighting activities in Indonesia, it is highly likely that children are involved in finding and collecting the crickets (Pemberton, 2003). These few observations raise important questions regarding the autonomous learning processes resulting from encounters between children and insects and the way in which these processes are incorporated into the acquisition of skills linked to adult activities."

In Southern Morocco, Simenel *et al.* (2017) show that beekeeping is a very important activity but that children are not allowed to manipulate beehives until they are late adolescents and must follow and observe the activities of their fathers. Due to these restrictions, children have developed a whole set of activities with solitary bees (a variety of species of the Megachilidae family) with whom they play, who they consider as their friends, and whose stores of pollen they collect and eat or sell to other children. These small solitary bees store their pollen in small empty shells of snails. Children's games involving solitary bees nurtures their fondness for beekeeping, a risky activity that they cannot yet afford to practice and can only observe through accompanying adult beekeepers. This example demonstrates that learning about the role of pollinators can start very early in childhood and that children are probably a key subset of all user groups at global level and in many biomes that develop their interest in nurturing and protecting plant-insects-human relationships.

and natural processes by science. Learning to transform nature has had both positive and negative impacts on quality of life. Genetically modified organisms, for example, have immediate positive impacts on the production of food and raw materials, but issues are arising about potential negative impacts on the environment (Pott *et al.,* 2018). Similarly, the use of gene drive techniques on mosquitoes, although not yet released *in situ*, are expected to have major benefits for human health (Hammond *et al.,* 2017), but such approaches are under debate due to ethical and environmental concerns.

NCP 16: Physical and Psychological Experiences

There are long held beliefs that human health and well-being are influenced positively by spending time in natural settings, and beneficial properties are attributed to activities in nature (Bishop, 2012; Stigsdotter *et al.,* 2011). Exposure in to nature in urban settings and is also thought to improve mental health, though reviews of scientific findings have been inconclusive about the extent of this effect and the elements of nature which might provide it (Gascon *et al.,* 2015; Lee & Maheswaran, 2011). Reflecting a growing recognition of the value of nature and cultural resources, the number and extent of protected areas established globally has increased. Over 30 million square kilometers have been protected in the last 50 years and the number of protected areas designated and/or recognized by countries has doubled every decade for the last 20 years (Deguinet *et al.,* 2014). Visitation to these protected areas has also increased. The world's terrestrial protected areas receive roughly 8 billion visits each year, more than 80% by European and North American visitors (Balmford *et al.,* 2015). These visits are estimated to generate approximately US $600 billion per year in direct in-country expenditure (Balmford *et al.,* 2015). Experience of nature has also been modified and popularized through the spa industry, mineral and natural springs, human-made gardens and forests, and many others (Erfurt-Cooper, 2010; Erfurt-Cooper & Cooper, 2009). This is one way of servicing the needs of the growing appetite for the experience of nature among affluent urban dwellers in the years to come. The establishment of protected areas, national parks, and tourist amenities such as spas are not always beneficial for traditional peoples whose lives are intertwined with nature (Laltaika & Askew, 2018). Protected areas and national parks can impoverish people and ultimately dispossess them from their homes and ultimately lead to the loss of ILK.

NCP 17: Supporting Identities

Nature provides culture with the possibility to attribute value to it, and culture attributes value to nature. The abundance of natural ecosystems, especially those with continued existence over longer periods of time, could be seen as a prerequisite for supporting identities. However, without culture this remains a potential only. Non-material and spiritual values are part of people's cultures and play a crucial role in shaping their perception of nature (Verschuuren *et al.,* 2010). In many cases identity is inseparably linked to a particular place or resource (such as Indigenous Peoples of the North and of the Pacific Islands). In these places, local economies depend strongly on the availability of natural resources, but also on cultural knowledge, traditionally transmitted from generation to generation, regarding the ways of preparation, storage, and distribution of food and resources (e.g., Kaltenborn, 1998; Pascua *et al.,* 2017). With increased globalization, urbanization, and environmental degradation these identities are at risk. Loss of identity has a direct impact on quality of life and human well-being and could result in health problems such as depression, alcoholism, suicide, and violence (Kirmayer *et al.,* 2011) and loss of security (IPBES, 2018b; Pascua *et al.,* 2017). At the same time, there seems to be an increasing awareness about cultural values, traditions, and environmental conservation, especially by urbanized and wealthy people who have otherwise become more distant from nature. High identity value results in better social cohesion, stronger sense of place, spiritual and cultural well-being, and thereby better care for the environment. Spiritual and religious values can be instrumental in promoting biodiversity conservation (Chan *et al.,* 2016; Daniel *et al.,* 2012; Hernández-Morcillo *et al.,* 2013), although there remains some risk for underestimating the complexities of lived experiences of spirituality and religiosity. Attempts have been made to use sacred areas as a point of departure when creating protected areas. There are important signs that youth, at least in the US, but also elsewhere, are rediscovering nature's contribution to identity (Wood *et al.,* 2010). Similarly, nature has become engrained in the cultural identity of some countries such as Bhutan (Zurick, 2006) and Costa Rica (Anglin, 2015), where NCP have been integrated into livelihoods and national economies.

NCP 18: Maintenance of Options

Preserving biodiversity is valuable in part because it maintains future options and potential for new discoveries. The loss of biodiversity reduces our options. Ehrlich (1992) compares biodiversity to a vast genetic library that has provided the very basis of our civilization—our crops, domestic animals and many of our medicines and industrial products but that "Innumerable potential new foods, drugs and useful products may yet be discovered—if we do not burn down the library first". (p.12). Preserving biodiversity preserves information embedded in genes and species. Information can provide global benefits because the results of new discoveries can be applied anywhere. We are losing many populations and species (see chapter 2.2) in taxonomic groups that have known value (Ceballos *et al.,* 2017) as well as those that have no know current value but may become important in the future. Measures of phylogenetic diversity, which give added weight to species with more unique genetic lineages, are also in decline (Faith *et al.,* 2018). Population extinctions and range contractions (an indicator of NCP18) are most severe in western North America, central Europe, India and Southeast Asia, south and central Australia, western and southern South America, and Northern and Southern Africa (Ceballos *et al.,* 2017).

2.3.5.4 Information gaps

Since the Millennium Ecosystem Assessment was published in 2005, a large amount of data have been collected on biodiversity, ecosystems, ecosystem services and more generally on the co-production and impact of social, environmental, and climate change upon them. Despite this progress, however, large information gaps remain in assessing the status and trends of NCP, and particularly their implications to the quality of life of different groups of people. Below are some of the major information gaps that should to be addressed going forward to improve future global assessments of NCP.

1. The extent of nature's contribution to good quality of life is not well understood for some NCP. The lack of understanding arises for several reasons. First, it is often hard to disentangle nature's contributions from other contributions. For example, though we have good data on status and trends of air quality across major cities in the world (WHO, 2016b), how changes in vegetation impact air quality in cities is less well understood and is currently a frontier of scientific investigation (Irga *et al.,* 2015; Janhäll, 2015). Second, understanding of key links between nature and impacts on good quality of life may be missing. For example, though we often have a good understanding of how changes in exposure affect disease incidence and impacts on human health, how changes in nature influence exposure is often complex and is poorly understood for some diseases (Bayles *et al.,* 2016). Exposure for vector-borne diseases depends on populations of vectors as well as how these vectors overlap with vulnerable populations of humans. Vector populations can depend on complex ecosystem interactions that give rise to unpredictable

increases or decreases in populations as a function of anthropogenic induced changes to ecosystems. Exposure also depends on human behavior and public health measures designed to reduce the vulnerability of human populations to disease.

2. Even where the extent of nature's contribution to good quality of life is well understood, there is often a lack of systematic data collection, or systematic documentation, on which to base a comprehensive global assessment. Much of the literature on non-material NCP involves detailed case studies of specific groups. This literature provides a wealth of information but studies typically differ in focus and methodology, and there is uneven coverage across regions, which makes it difficult to combine results into a systematic global assessment (Hernández-Morcillo *et al.,* 2013). For most NCP we lack systematic reporting on impacts of nature on good quality of life. Much of the natural science literature focuses on changes in ecosystems and biodiversity but does not report how these changes affects good quality of life. Much of the systematic data reporting on various aspects of good quality of life (such as income, livelihoods, health, and education) does not disentangle the impacts of nature on good quality of life from other impacts. It would be ideal to report quantitative measures of NCP in terms readily understood by various decision makers and the general public. While we have some measures of NCP reported in monetary terms, health terms, or other measures related to good quality of life, we lack systematic indicators that can be reported in a variety of easily understood metrics for many NCP.

3. A general issue in doing a comprehensive global assessment is the existing fragmented state of knowledge with lack of integration between social and natural sciences, and between western science and ILK. This assessment has emphasized the importance of including multiple viewpoints and sources of knowledge, but this has not been matched with an ability to effectively integrate multiple sources of knowledge into a systematic assessment. Different world views are hard to integrate in substantive ways. Doing so will require increased dialog across communities and agreement on how to be more systematic in knowledge generation and data collection.

4. The distribution across user groups of impacts of NCP on good quality of life are poorly documented. The original intent of this assessment was to report on impacts on good quality of life by major user groups by region. A typology of user groups was developed for this assessment, which involved differentiation based on livelihoods (subsistence gatherers, subsistence and commercial farmers, subsistence and commercial fishers, pastoralists, commercial ranchers, commercial foresters, mining and energy production, commercial and manufacturing), as well as residence location (rural, semi-urban, urban, coastal, inland, forest, grassland, desert, etc.). However, there has not been enough systematic study of impacts of NCP on good quality of life by user groups to date to allow such reporting. Many existing studies of NCP report on overall changes and do not break down impacts by user groups. In addition, though there is a rich literature on studies of particular groups and in particular places by anthropologists and other social scientists, as well as written material documenting ILK, but this information has not been systematically reported in a common framework that would allow for a comprehensive global assessment. Improvements in the ability to report on impacts by user groups would greatly improve the usefulness of future assessments.

5. Measuring trends in NCP requires having a time series of data measured in a consistent fashion. Consistent time series data exists for some aspects of some NCP but is lacking for many aspects of most NCP. For some environmental measures it is now possible to get consistent global data via remote sensing. However, many remote sensing data series begin with the satellite era, so that many of these time series are of fairly short duration. In contrast, measures of impact on good quality of life often require direct observation or survey work. Time series data exists for income, health and other measures of human well-being but typically does not report on the impact that nature has on good quality of life.

2.3.6 INTEGRATIVE SUMMARY AND CONCLUSIONS

Nature provides not only the basic elements needed for human survival, but also contributes material and non-material benefits that improve human well-being. Nature's contributions to people (NCP) include i) regulation processes that control the production of important elements for human well-being such as fresh air, potable water, shelter, and control of pests, ii) material goods such as the provisioning of food and energy resources, medicines, and construction materials, and iii) non-material value such as opportunities for learning, having experiences, and instilling a sense of identity. All these contributions rely to some extent on the biophysical properties of nature (e.g., ecosystems, populations, species) but also on human-nature interactions, which together define the co-production and outputs of NCP **(Figures 2.3.1, 2.3.2)**. For an NCP to positively impact quality of life it must be available, accessible, and valued.

The output of co-production for most of the regulating and non-material NCP have decreased since 1970. Only NCP that are related to the co-production of marketable goods show consistent increasing trends (i.e., materials, food and feed, and energy) **(Figure 2.3.3)**. Nevertheless, although the outputs of co-production have increased for most material NCP, the long-term ability of nature to continue producing these NCP has declined. For example, production of farmed fish has increased over the past 10 years, offsetting declines of about 10% in wild catch that reflect an estimated decrease of 6-30% in catch potential resulting from over-harvesting fish stocks. Potential NCP for ocean acidification regulation has remained stable or may have increased over the last few decades, as there was an increase in global marine primary production linked to multi-decadal variability in ocean climate (Chavez *et al.,* 2011), while 14 of 18 potential NCP have declined and others show contrasting trends across different proxies.

There is increasing recognition and awareness of the importance of NCP for a good quality of life. Declines in NCP have led to purposeful actions to try to arrest the decline, such as increasing amounts of protected areas, and efforts to maintain mangroves and coastal wetlands to provide protection against storm surge for coastal settlements and initiatives to protect 'blue carbon' stores in coastal ecosystems (Kennedy *et al.,* 2010). Nevertheless, overall trends continue downward for many NCP despite these actions, as they are outweighed by continued negative actions arising from population pressures, market forces, or system inertia.

In many circumstances there are trade-offs among NCP. For example, although an increment of cultivated areas has been shown to increase the provisioning of food and other materials important for people (e.g., natural fibers, ornamental flowers), it is also likely to reduce contributions of nature such as pollination by wild insects, pest control, and regulation of water quality. Agroecological means of producing food may reduce these trade-offs.

Tropical and subtropical regions seem to be suffering the most pronounced changes, as shown by the high number of NCP showing negative trends there. Deforestation, land conversion, and defaunation are the main factors behind the observed patterns. Differences in how trends in NCP affect quality of life across user groups are substantial, however, scarcity of data to date prevents a systematic review. These differences in impact arise because NCP accessibility and associated value are context dependent and vary with cultural preferences, knowledge, socioeconomic status, and geographical location as well as other drivers. Integration among natural and social science is needed to better assess the impact of NCP on quality of life. Also, further steps should be directed at reducing uncertainty of trends for both co-production and potential NCP. Taking into account likely trade-offs, it is critical to understand, integrate, and synthesize information across all NCP.

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Chapter **3.**

ASSESSING PROGRESS TOWARDS MEETING MAJOR INTERNATIONAL OBJECTIVES RELATED TO NATURE AND NATURE'S CONTRIBUTIONS TO PEOPLE

IPBES GLOBAL ASSESSMENT REPORT ON BIODIVERSITY AND ECOSYSTEM SERVICES
CHAPTER 3. ASSESSING PROGRESS TOWARDS MEETING MAJOR INTERNATIONAL OBJECTIVES RELATED TO NATURE AND NATURE'S CONTRIBUTIONS TO PEOPLE

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CHAPTER **3**

ASSESSING PROGRESS TOWARDS MEETING MAJOR INTERNATIONAL OBJECTIVES RELATED TO NATURE AND NATURE'S CONTRIBUTIONS TO PEOPLE

EXECUTIVE SUMMARY

In recognition of the importance of nature, its contributions to people and role in underpinning sustainable development, governments adopted a Strategic Plan on Biodiversity 2011–2020 through the Convention on Biological Diversity (CBD) containing 20 'Aichi Biodiversity Targets' and integrated many of these into the Sustainable Development Goals (SDGs) adopted through the United Nations in 2015. Additional multilateral environmental agreements (MEAs) target particular aspects of nature (e.g., Ramsar Convention on Wetlands; Convention on Migratory Species), drivers of biodiversity loss (e.g., Convention on International Trade in Endangered Species of Wild Fauna and Flora), or responses (e.g., World Heritage Convention). These various MEAs provide complementary fora in which governments strive to coordinate efforts to reduce the loss and degradation of nature, and to promote sustainable development. In this chapter, we assess, through a systematic review process and quantitative analysis of indicators, progress towards the 20 Aichi Targets under the Strategic Plan (and each of the 54 elements or components of these targets), targets under the SDGs that are relevant to nature and nature's contributions to people (NCP), and the goals and targets of six other MEAs. We consider the relationships between the SDGs, nature and the contributions of Indigenous Peoples and Local Communities (IPLCs) to achieving the various targets and goals, the impact of progress or lack of it on IPLCs, the reasons for variation in progress, implications for a new Strategic Plan for Biodiversity beyond 2020, and key knowledge gaps.

1 **There has been good progress towards the elements of 4 of the 20 Aichi Biodiversity Targets under the Strategic Plan for Biodiversity 2011–2020. Moderate progress has been achieved towards some elements of another 7 targets, but for 6 targets poor progress has been made towards all element. There is insufficient information to assess progress towards some or all components of the remaining 3 targets (*established but incomplete*) {3.2}. Overall, the state of nature continues to decline (12 of 16 indicators show significantly worsening trends) (*well established*) {3.2}.** Of the 54 elements, we have made good progress towards five (9%), moderate progress towards 19 (35%) and poor progress or movement away from the target for 21 (39%). Progress is unknown for nine elements (17%). The strongest progress has been towards identifying/prioritizing invasive alien species (Target 9), increasing protected area coverage (Target 11), bringing the Nagoya Protocol into force (Target 16), and developing national biodiversity strategy and action plans (Target 17). However, while protected areas now cover 15 per cent of terrestrial and freshwater environments and 7 per cent of the marine realm, they only partly cover important sites for biodiversity and are not yet fully ecologically representative, well-connected and effectively or equitably managed *(well established)* {3.2}. While some species have been brought back from the brink of extinction (contributing towards Target 12 on preventing extinctions), species are moving towards extinction at an increasing rate overall for all taxonomic groups with quantified trends (*well established*) {3.2}. Least progress has been made towards Target 10 (addressing drivers impacting coral reefs and other ecosystems vulnerable to climate change); *(established but incomplete)* {3.2}.

2 **In addressing the Aichi Biodiversity Targets, more progress has been made in adopting and/or implementing policy responses and actions to conserve and use nature more sustainably (22 of 34 indicators show significant increases) than has been achieved in addressing the drivers of biodiversity loss (9 of 13 indicators show significantly worsening trends) (*well established*) {3.2}. As a result, the state of nature overall continues to decline (12 of 16 indicators show significantly worsening trends) (*well established*) {3.2}.** Indicators for the Targets under Goal B

addressing anthropogenic drivers of biodiversity loss, including habitat loss (Target 5), fisheries (6), agriculture, aquaculture and forestry (7), pollution (8) invasives (9) show that many of these drivers are increasing despite efforts to meet the Targets (*established but incomplete)* {3.2}. Trends over time in the magnitude of nature's contributions to people are less well known, but four of five indicators show significantly worsening trends (*established but incomplete)* {3.2}.

3 **In some cases, it is possible to quantify what the trends would have been in the absence of conservation action and policy responses to the Aichi Biodiversity Targets {3.2}, but in most cases there is insufficient information.** For example, for Target 12, extinction risk trends shown by the Red List Index for birds and mammals would have been worse in the absence of conservation, with at least six ungulate species (e.g., Arabian Oryx and Przewalski's Horse) likely to now be extinct or surviving only in captivity without conservation during 1996–2008. For Target 9, at least 107 highly threatened birds, mammals, and reptiles (e.g., Island Fox and Seychelles Magpie-Robin) are estimated to have benefited from invasive mammal eradications on islands {3.2}. A recent model estimated that conservation investment during 1996–2008 reduced biodiversity loss (measured in terms of changes in extinction risk for mammals and bird) in 109 countries by 29% per country on average {3.2}. However, there are few other counterfactual studies assessing how trends in the state of nature or pressures upon it would have been different in the absence of conservation efforts, meaning that it is often difficult to quantify the impact of actions taken towards the Aichi Biodiversity Targets (*well established*) {3.2}.

4 **Nature is essential for achieving the Sustainable Development Goals, either directly through clean water, climate action, life below water and life on land (Goals 6, 13, 14, 15, respectively) or through more complex relationships and contributions to ending poverty and hunger, improving health and well-being, and sustainable cities (Goals 1, 2, 3, 11, respectively) *(established but incomplete)* {3.3.2.1; 3.3.2.2}.** For several targets to end poverty and hunger and enhance health and well-being; nature and its contributions play an important role (e.g., through reducing vulnerability, increasing agricultural productivity and nutrition, as a source of traditional medicine or novel compounds, or by regulating water and air quality). However, the role of nature's contribution for specific targets is variable across regions, societies and ecosystems, and strongly dependent on governance and other inputs / assets. Improved understanding of these interactions and associated positive and negative feedbacks across space and time, is a key knowledge gap.

5 **For the 44 SDG targets assessed, including targets for poverty, hunger, health, water, cities, climate, oceans and land (Goals 1, 2, 3, 6, 11, 13, 14, 15), findings suggest that current negative trends in nature will substantially undermine progress to 22 SDG targets and result in insufficient progress to meet 13 additional targets (i.e. 80 per cent (35 out of 44) of the assessed targets) {3.3.2.1; 3.3.2.2} *(established but incomplete).*** Across terrestrial, aquatic and marine ecosystems, current negative trends in nature and its contributions will hamper SDG progress, with especially poor progress expected towards targets on water security, water quality, ocean pollution and acidification. Trends in nature's contributions relevant to extreme event vulnerability, resource access, small-scale food production, and urban and agricultural sustainability are negative and insufficient for achieving relevant targets under SDGs 1, 2, 3, and 11. This has negative consequences for both the rural and urban poor who are also directly reliant on declining resources for consumption and income generation {3.3.2.2}. For a further 9 targets evaluated in SDGs 1, 3 and 11 a lack of knowledge on how nature contributes to targets (4 targets) or gaps in data with which to assess trends in nature (5 targets) prevented their assessment.

6 **Important positive synergies between nature and goals on education, gender equality, reducing inequalities and promoting peace and justice (Sustainable Development Goals 4, 5, 10 and 16) were found {3.3.2.3} (*established but incomplete*). Despite overwhelming evidence of the linkages between nature, NCP and development, the current focus and wording of targets in these goals obscures or omits their relationship to nature, thereby preventing their assessment here.** Important positive synergies at the goal level were found to exist for Goals 4, 5, 10, 16 from studies of access to nature and educational outcomes, land or resource tenure and gender equality, and the availability of nature's contributions and conflict resolution. There is a critical need to include these linkages in future policy targets, as well as to develop more fit-for-purpose indicators and datasets, especially socially disaggregated data to capture impacts on equity related to SDGs and the Agenda 2030 aim to "leave no one behind".

7 **In assessing the impacts of SDG achievement on nature and its contributions, Goals 7, 8, 9, 12 (relating to energy, economic growth, industry and infrastructure, and consumption, and production) could have substantial positive or negative impacts on nature and therefore on the achievement of other Sustainable Development Goals. The nature and magnitude of this impact will depend on approaches chosen to achieve these goals {3.3.2.4} (*well established*). This is also the case for aspects of Goals 1 (ending poverty), 2 (ending hunger), and Goal**

11 (sustainable cities) and their potential impacts on nature. Across SDGs assessed, some evidence suggests that approaches that enhance nature and its contributions, in combination with investments in anthropogenic assets, can help meet multiple SDGs, often simultaneously {3.3.2.2} *(established but incomplete).* New agroecological farming approaches, certain clean energy technologies, improvements in grey and green infrastructure, and improved management of marine ecosystems and fisheries are among approaches found to have positive impacts across multiple SDG targets. While we have good evidence on the impacts on nature of previous efforts to achieve development goals, lack of information on the approaches to be used to achieve the SDGs makes it not currently possible to assess their impacts on nature, nature's contributions to people and other SDGs. Efforts to achieve Goals 6, 13, 14, 15 will likely have positive effects on nature and NCP. However, if these efforts do not consider factors such as access, equity or power they can have negative impacts on the poor and several other SDGs related to poverty and equity. Issues of land and resource tenure, water security and entitlements, and secure access to resources are likely to increase in importance for efforts to reduce vulnerability and prevent worsening poverty, particularly in regions impacted most strongly by climate change.

8 **There has been mixed progress towards achieving the goals of the Convention on Migratory Species, Convention on International Trade in Endangered Species of Wild Fauna and Flora, International Plant Protection Convention, United Nations Convention to Combat Desertification, the Ramsar Convention on Wetlands, and the World Heritage Convention (*established but incomplete*) {3.4}.** In addition, only one in five of the strategic objective and goals across six global agreements relating to nature and its contributions to people are demonstrably on track to be met. For nearly one third of the goals of these conventions there has been little or no progress towards them or, instead, movement away from them (*established but incomplete*) {3.4}. Progress has been most positive for the World Heritage Convention {3.4}.

9 **Given their direct material and cultural links to the environment, Indigenous Peoples and Local Communities (IPLCs) are and will continue to be disproportionately impacted if the Aichi Biodiversity Targets and SDGs are not met (*well established*) {3.2, 3.3}. Furthermore, formal incorporation of IPLCs, their many locally attuned management systems, and indigenous and local knowledge (ILK) into environmental management has been shown to offer effective means to reduce environmental degradation (*well established*) {3.2, 3.3}.** Examples of negative impacts on IPLCs from insufficient progress towards meeting the Aichi Biodiversity Targets and SDGs include continued loss of subsistence and livelihoods from ongoing deforestation (Target 5, SDG 15) and unsustainable fishing practices (Target 6, SDG 14), and impacts on health from pollution and water insecurity (Target 8, SDGs 6 and 12). Examples of the contributions of IPLCs to sustainable environmental management include community forestry initiatives (Target 7, SDG 12), traditional agriculture and aquaculture systems (Target 7, SDG 12), 'Indigenous Peoples' and community conserved territories and areas' (ICCAs; Target 11, SDGs 14 and 15), integration of indigenous and local knowledge into invasive and threatened species' management (Targets 9 and 12; SDGs 14 and 15), and conservation of wild and domestic animal and plant genetic diversity through market and non-market exchanges (Target 13, SDG 2) {3.2, 3.3}.

10 **Progress towards Aichi, SDG and other MEAs' targets related to marine and terrestrial conservation and restoration has mostly been poor to moderate (*well established*) {3.2, 3.3, 3.4}.** While good progress has been made in the implementation of some actions and policy responses, marine biodiversity continues to face multiple threats from human activities, including habitat loss and degradation, unsustainable fisheries, invasive alien species, pollution, and climate change, with consequent biodiversity loss (*well established*). Coastal fishery stock depletion and ecosystem degradation has had negative consequences for the well-being of both low-income populations and Indigenous Peoples and Local Communities in terms of food security, spiritual and social integrity, vulnerability to climate change, and livelihoods (*well established*) {3.2, 3.3}. Progress towards targets relating to conservation and restoration of terrestrial and freshwater ecosystems is varied across different target elements. While trends in some responses have been positive, there has been poor to moderate progress towards key aspects of protected areas, sustainable production/ management systems (particularly in agriculture, aquaculture and forestry), and in restoring ecosystems, preventing extinctions, addressing species declines, ensuring health, food and water security, and building resilience amongst vulnerable populations (*well established*) {3.2, 3.3, 3.4. 3.5}.

11 **A number of drivers and threats are hindering progress towards achieving conservation of nature, sustainable delivery of nature's contributions, and achievement of the Aichi Biodiversity Targets, SDGs and objectives of other MEAs.** Ecosystem loss and degradation—driven in particular by agricultural expansion and intensification, unsustainable forestry and commercial and residential development— is the major driver of deteriorations in the state of nature that hinder progress to targets aiming to sustain life on land and preventing extinctions (*well established*) {3.2, 3.3}. Unsustainable use and trade in species, including illegal poaching and trafficking, is a particular driver for exploited terrestrial and

freshwater species and ecosystems, (*well established*) {3.2, 3.3}. Marine species and ecosystems are also substantially impacted by unsustainable harvest, both for targeted species and those impacted indirectly through bycatch or effects on food supply (*well established*) {3.2, 3.3}. Insufficient progress has been made to targets addressing the spread of invasive alien species and to mitigate their impacts on native species (*well established*) {3.2, 3.3}. Pollution continues to negatively impact ecosystem integrity, species populations and human well-being, with plastics emerging as a particular issue, especially in the marine realm (*well established*) {3.2, 3.3}. Despite availability of appropriate technologies and public awareness of the impact of pollution on nature and human well-being, only moderate progress has been made in reducing/abating different forms of pollution (*well established*) {3.2, 3.3}.

12 **To meet the Sustainable Development Goals and achieve the 2050 Vision for Biodiversity, future targets are likely to be more effective if they take into account the impacts of climate change. Climate change is exacerbating other threats and hindering our ability to meet many Sustainable Development Goals and Aichi Biodiversity Targets including those related to fisheries, invasive alien species, reefs, protected areas, preventing extinctions, and ecosystem resilience (6, 9, 10, 11, 12 and 15, respectively) (*well established*) {3.2, 3.3}.** Shifts in species' distributions, changes in phenology, altered population dynamics, and other disruptions scaling from genes to ecosystems are already evident in marine, terrestrial and freshwater systems (*well established*) {3.2}. Almost half (47%) of terrestrial non-volant threatened mammals and 23.4% of threatened birds may have already been negatively impacted by climate change in at least part of their distribution (*established but incomplete*) {3.2}. Projected impacts suggest that climate change will increase the number of species under threat, with most studies concluding that there are likely to be fewer species that expand their ranges or experience more suitable climatic conditions than the number that experience range contraction or less suitable conditions (*established but incomplete*) {3.2}. Few protected areas are currently taking into account climate change in their objectives or management, but the effects of climate change on protected areas will continue exacerbating existing threats (*established but incomplete*). These trends, combined with the direct impacts of climate change, will negatively affect the achievement of SDGs including those related to poverty, health, water and food security, affecting in particular low-income populations and IPLCs.

13 **Progress to different goals and targets, as well as between regions, was variable {3.6}. Good progress on goals related to policy responses and actions to conserve nature and use it more sustainably were countered by substantial negative trends in drivers of change in nature and NCP, producing generally negative trends in the state of nature and many aspects of NCP (*well established*) {3.2, 3.3, 3.4}.** Reasons for this variation are multiple and interacting, including the sectoral, spatial and temporal mismatches between the responses assessed (e.g., protected areas) and drivers of change (e.g., agricultural expansion). Furthermore, evidence suggests that trends in drivers and nature would be worse without the responses implemented. Poor to moderate progress in effectively implementing some responses is an important constraint, including reducing harmful subsidies, providing positive incentives, sharing technologies, mobilizing financial resources, sustainably managing natural resources, ensuring equity, and strengthening the role of nature and NCP in reducing impacts from disasters. Regionally, there were no consistent patterns, with some regions showing greater progress towards some targets but not for others. Ensuring that policies are coherent between different sectors would enable better alignment of targets and goals (mainstreaming) relating to biodiversity in national and regional planning.

14 **Future targets in a new post-2020 global biodiversity framework may be more effective if they: have clear, unambiguous, simple language, with quantitative elements; take account of synergies and trade-offs between targets, are formulated to capture aspects of nature and NCP relevant to GQL, take greater account of socioeconomic and cultural contexts and values; take account of climate change impacts and responses; and integrate insights from the conservation science community as well as social scientists, indigenous and local knowledge, and non-academic stakeholders and take account of the availability of existing indicators and the feasibility of developing new ones (*established but incomplete*) {3.7}.** Identifying and securing synergies between targets, and minimizing trade-offs, would maintain options for co-benefits before they are reduced by increasing human impacts (*established but incomplete*) {3.7}. Increasing consideration of values and drivers in the context of policies and decision-making when setting targets may help to reduce lack of political cooperation, inadequate economic incentives, and inadequate involvement of civil society. Future targets will be more effective if they take climate change into account, considering both the potential consequences for biodiversity of climate change mitigation policies and actions, and the need to integrate adaptation. Alternative approaches to the process of target-setting (e.g., nationally determined contributions) may also be considered {3.7}.

15 **Key knowledge gaps make it more challenging to determine progress towards the Aichi Biodiversity Targets and Sustainable Development Goals and limit our ability to implement responses more effectively**

(*well established*) {3.8}. We lack quantitative indicators to judge progress towards some elements of 13 Aichi Biodiversity Targets, and over one third (19/54, 35%) of all elements across all Targets *(well established)* {3.2}, meaning that assessment of these elements relies on more qualitative assessment of the literature. For Target 15 (ecosystem resilience and contribution of biodiversity to carbon stocks), the lack of both quantitative indicators and qualitative information means that no assessment of progress was possible {3.2}. Key knowledge gaps include trends in harmful subsidies, patterns in the intensity of unsustainable exploitation of species and ecosystems, effectiveness and equity of management of protected areas and other area-based conservation mechanisms, extinction risk and trends of many species (particularly invertebrates, plants and fungi), trends in the genetic diversity of utilised species, ecosystem resilience, Access and Benefits-Sharing of genetic resources, integration of indigenous and local knowledge in assessment and monitoring, extant and effectiveness of participation of indigenous and local communities in governance, trends in many categories of nature's contributions to people, and regional patterns of progress (*established but incomplete*) {3.2, 3.3, 3.8}. Gaps in knowledge also precluded assessment of 9 out of 44 targets under the SDGs reviewed, and there is inadequate understanding of the relationships between nature (and its contributions to people) and the achievement of some SDGs, and vice versa (*established but incomplete*) {3.3, 3.8}.

3.1 INTRODUCTION

3.1.1 Premise

Evidence shows that in the past 50 years, human development gains have been substantial but largely achieved at growing costs to losses in biodiversity, degradation of many of nature's regulating and non-material contributions to people (NCP), displacements of indigenous and local populations, exacerbation of poverty for certain groups of people, and extensive human rights and social justice violations. The level of planetary change is unprecedented and may push the Earth system into a new state (Steffen *et al*.,2015).

In light of the importance of nature and NCP, governments have developed many multilateral environmental agreements (MEAs) to motivate actions to sustain nature and its contribution to the promotion of long-term equitable human well-being and sustainable development. Notably, the Aichi Biodiversity Targets, and a range of other related agreements (see section 3.1.4 below). These provide a foundation to implement actions at the national, regional, and international level. While there are many synergies and shared goals between these environmental agreements and global development policies, their execution is largely uncoordinated requiring efforts to better align them (UNEP 2016c). In response, the United Nations Agenda 2030 and its Sustainable Development Goals (SDGs) have been developed as a comprehensive policy framework which unifies multiple agreements including goals related to nature and nature's contributions to people. It is therefore an important policy framework for IPBES in its ability to contribute to the conservation and sustainable management of nature and NCP.

In this chapter, we review evidence available for assessing progress towards meeting major international objectives related to nature and NCP. We focus specifically on the Aichi Biodiversity Targets and relevant SDGs, as well as relevant objectives of other agreements. This includes an assessment of both regional and distributional patterns as well as indigenous and local knowledge. We then synthesize the patterns across goals and targets, review the implications of our results for a new Strategic Plan for Biodiversity and the post-2020 agenda, and finally summarize knowledge gaps and needs for further research and capacity-building.

Below, we briefly summarise some of the agreements with relevance to IPBES and outline our approach to their assessment. These agreements include the Aichi Biodiversity Targets agreed through the Convention on Biological Diversity (CBD), the SDGs, other relevant conventions. We also consider the role of Indigenous Peoples and Local Communities (IPLCs) in achieving these agreements. We intentionally focus in more detail on IPLCs (compared with other sectors of society such as business, NGOs, women, civil society) because of the mandate of the IPBES global assessment; however, we acknowledge the critical importance of these other sectors in relation to meeting targets of these agreements.

3.1.2 Aichi Biodiversity Targets

In October 2010, the tenth meeting of the Conference of the Parties of the Convention on Biological Diversity (CBD) adopted a revised and updated Strategic Plan for Biodiversity, including the Aichi Biodiversity Targets, for the 2011–2020 period (CBD, 2010a). The Plan provides an overarching framework on biodiversity, including for the biodiversity-related Conventions as well as the entire United Nations system. The vision of this Plan is of a world 'living in harmony with nature' where 'by 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people'. A central element of this framework is facilitating the implementation of coherent National Biodiversity Strategies and Action Plans (NBSAPs), instruments for translating the global Strategic Plan to national circumstances, including through national targets, and a deep integration of aspects of biodiversity conservation into sectoral policies.

As presented in **Table 3.1**, the 20 headline targets of the Strategic Plan for 2015 or 2020 (the 'Aichi Biodiversity Targets'), are organized under five strategic goals.

To help monitor progress towards achieving the Aichi Biodiversity Targets, the CBD developed an indicative list of indicators (CBD, 2012a), building on those used to assess whether the 2010 Biodiversity Target was met in the Global Biodiversity Outlook 3 (GBO-3) (Butchart *et al*., 2010; Secretariat of the Convention on Biological Diversity, 2010). A mid-term evaluation of progress against the Aichi Biodiversity Targets using some of these indicators (Tittensor *et al*., 2014) formed the basis of the assessment published in the Global Biodiversity Outlook-4 (Secretariat of the Convention on Biological Diversity, 2014). This list of indicators was further considered and revised by the CBD COP in 2016 (see Decision XIII/28; CBD, 2016a). In this chapter, we extend and expand the analysis of Tittensor *et al*. (2014), using updated time series for most indicators, and incorporating additional indicators to fill gaps. We also review the literature more generally for information on progress towards the Targets and draw on assessments of countries' National Reports to the CBD.

3.1.3 SDGs

In 2015, the United Nations' 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals

Table 3 1 **The Convention of Biological Diversity 2011-2020 Aichi Biodiversity Targets.**

Strategic Goal A: Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society	
1	By 2020, at the latest, people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably.
2	By 2020, at the latest, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems.
3	By 2020, at the latest, incentives, including subsidies, harmful to biodiversity are eliminated, phased out or reformed in order to minimize or avoid negative impacts, and positive incentives for the conservation and sustainable use of biodiversity are developed and applied, consistent and in harmony with the Convention and other relevant international obligations, taking into account national socio economic conditions.
4	By 2020, at the latest, Governments, business and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption and have kept the impacts of use of natural resources well within safe ecological limits.
Strategic Goal B: Reduce the direct pressures on biodiversity and promote sustainable use	
5	By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced.
6	By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits.
7	By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity.
8	By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.
9	By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.
10	By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.
Strategic Goal C: To improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity	
11	By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.
12	By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained.

13	By 2020, the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socioeconomically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity.
Strategic Goal D: Enhance the benefits to all from biodiversity and ecosystem services	
14	By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable.
15	By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.
16	By 2015, the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization is in force and operational, consistent with national legislation.
Strategic Goal E: Enhance implementation through participatory planning, knowledge management and capacity-building	
17	By 2015 each Party has developed, adopted as a policy instrument, and has commenced implementing an effective, participatory and updated national biodiversity strategy and action plan.
18	By 2020, the traditional knowledge, innovations and practices of indigenous and local communities relevant for the conservation and sustainable use of biodiversity, and their customary use of biological resources, are respected, subject to national legislation and relevant international obligations, and fully integrated and reflected in the implementation of the Convention with the full and effective participation of indigenous and local communities, at all relevant levels.
19	By 2020, knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are improved, widely shared and transferred, and applied.
20	By 2020, at the latest, the mobilization of financial resources for effectively implementing the Strategic Plan for Biodiversity 2011-2020 from all sources, and in accordance with the consolidated and agreed process in the Strategy for Resource Mobilization, should increase substantially from the current levels. This target will be subject to changes contingent to resource needs assessments to be developed and reported by Parties.

was adopted at the UN Sustainable Development Summit (UN, 2015; **Table 3.2**). This agenda built on the previous Millennium Development Goals (MDGs) but went further in making the goals universal to apply to all countries and all people – not just developing countries as was the case with the MDGs. Furthermore, they integrate all three dimensions of sustainable development: social, economic and environmental into a unified 'plan of action for people, planet, and prosperity'. The 2030 Agenda and its SDGs goes beyond the poverty alleviation focus of the MDGs to address inequalities, economic growth, decent jobs, cities and human settlements, industry and infrastructure, oceans, ecosystems, energy, climate change, sustainable consumption and production, peace and justice.

In this more integrated approach, nature and its contributions to people are clearly critical to achieving many SDGs (Balvanera *et al*., 2016; Pascual *et al*.,2017; Pérez & Schultz, 2015; Smith *et al*.,2017 ; Wood *et al*., 2018). Furthermore, approaches to achieve the SDGs will have positive and/or negative impacts on nature and NCP. These relationships and feedbacks between nature, NCP and SDGs, as well as feedbacks between attempts to meet the SDG targets, and nature and NCP, are complex, often cross-scale and are typically overlooked (Guerry *et al*., 2015).

In this chapter we focus on the assessment of how trends in nature and its contributions to people affect our ability to achieve particular SDGs. We further assess how the achievement of SDGs affects nature and its contributions to people. In recognizing that the SDGs are complex and interrelated, we adopt an integrated approach to assessment as outlined in section 3.3 below.

Table 3 2 **The United Nations 2030 Sustainable Development goals.**

1 NO POVERTY	End poverty in all its forms everywhere	10 REDUCED INEQUALITIES	Reduce inequality within and among countries
2 ZERO HUNGER	End hunger, achieve food security and improved nutrition and promote sustainable agriculture	11 SUSTAINABLE CITIES AND COMMUNITIES	Make cities and human settlements inclusive, safe, resilient and sustainable
3 GOOD HEALTH AND WELL-BEING	Ensure healthy lives and promote well-being for all at all ages	12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Ensure sustainable consumption and production patterns
4 QUALITY EDUCATION	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	13 CLIMATE ACTION	Take urgent action to combat climate change and its impacts
5 GENDER EQUALITY	Achieve gender equality and empower all women and girls	14 LIFE BELOW WATER	Conserve and sustainably use the oceans, seas and marine resources for sustainable development
6 CLEAN WATER AND SANITATION	Ensure availability and sustainable management of water and sanitation for all	15 LIFE ON LAND	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
7 AFFORDABLE AND CLEAN ENERGY	Ensure access to affordable, reliable, sustainable and modern energy for all	16 PEACE, JUSTICE AND STRONG INSTITUTIONS	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
8 DECENT WORK AND ECONOMIC GROWTH	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	17 PARTNERSHIPS FOR THE GOALS	Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation		

3.1.4 Other global agreements related to nature and nature's contributions to people

Conserving nature, and hence nature's contributions to people, is the goal of many other Conventions and agreements. More than 700 Multilateral Environmental Agreements (MEAs) have been adopted between 1868 and 2011 (Gomar, 2016; Kim, 2013), around 150 of which are related to nature (Gomar, 2016). Most of these nature-related MEAs focus on specific issues and geographic regions. In 2004, seven MEAs operating at a global scale created the Liaison Group of Biodiversity-related Conventions (Caddell, 2012) to improve 'implementation of and cooperation among the biodiversity-related Conventions' (CBD, 2018g). The group consists of the following set (abbreviations and year in which each one entered into force are given in parentheses): the Convention on Biological Diversity (Convention on Biological Diversity, 1992), Convention on the Conservation of Migratory Species of Wild Animals, also known as the Convention on Migratory Species (CMS), Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 1975), International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA, 2004), Ramsar Convention on Wetlands (Ramsar, 1971), World Heritage Convention (WHC, 1972), and the International Plant Protection Convention (IPPC, 1952).

In this chapter, we assess progress towards the goals and targets of these MEAs, plus the United Nations Convention to Combat Desertification (UNCCD, 1994) (section 3.4). Although UNCCD does not have nature as its core goal, its mission and vision include nature-based solutions and sustainable actions and its implementation has a significant impact on nature, nature's contributions to people, and livelihoods. Given that none of these Conventions explicitly focuses on the marine realm, we consider progress towards elements of articles 61–66 of the United Nations Convention on the Law of the Sea (UNCLOS) that relate most closely to the conservation of nature **(Box 3.1)**. Finally, given the global importance of conserving polar regions, we also review progress towards achieving the objectives of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) and the Arctic Council's Conservation of Arctic Flora and Fauna (CAFF, **Box 3.2**). While we acknowledge that other agreements, including United Nations Framework Convention on Climate Change, contribute to this sphere, they are beyond the scope of this exercise.

The 11 global multilateral environmental agreements covered by this chapter together address both fauna and flora in all biomes including agricultural lands, cities, and rangelands. For each goal under each MEA, we assess progress through reviewing relevant indicators from sections 3.2 (on the Aichi Biodiversity Targets) and 3.3 (on the SDGs), systematically reviewing the available literature, and drawing on assessments of countries' reports to Convention secretariats. Hence, we use a broad evidence base, both quantitative and qualitative to assess progress. We score progress to each goal or objective against a three-point scale (good, moderate, little/no; see below for definitions). The breadth of these categories allows for greater accuracy in categorizing progress, given the subjective nature and incomplete information for many of the goals and objectives.

3.1.5 Why the Aichi Biodiversity Targets and Sustainable Development Goals are important from the perspective of Indigenous Peoples and Local Communities

A growing body of research shows that biodiversity loss and unsustainable use have led to severe hardship among IPLCs and that Indigenous Peoples lag behind on virtually every social and economic indicator addressed in the SDGs, including health, education, employment, human rights, right to access lands and natural resources (Thaman *et al*., 2013). For example, using the scarce available national data, the 2009 and the 2015 United Nations Reports on the 'State of the World's Indigenous Peoples' (UNPFII, 2009; UNPFII, 2015) noted that while there are 370 million Indigenous Peoples (5% of the world's population), they represent about one third of the world's 900 million extremely poor rural people (UNPFII, 2009). While estimates about the number of people that could be classified as local communities are not available, estimates based on customary tenure or community-based regimes (often overlapping with government land) suggest that over 1 billion people could fall in such category (see chapter 1), a significant share of which are considered rural poor. Similarly, IPLCs experience poorer health and social outcomes than non-indigenous populations, although the magnitude of the differences vary according to the indicator (Anderson *et al*., 2016; Coimbra *et al*., 2013; Gracey & King, 2009). On the other hand, IPLCs manage or have tenure rights over at least 28% of the global land area, including at least 40% of the area that is formally protected, and about 37% of ecologically intact landscapes. Consequently, adequate progress to both the SDGs and Aichi Biodiversity Targets are crucially important to IPLCs, and a major international effort is also needed to increase the recognition of IPLCs at national and international levels so as to provide a strong base for policy development and monitoring (Madden *et al*., 2016).

Conventions to ensure biodiversity conservation (i.e., the CBD) and to achieve sustainable development (i.e., the SDGs) are of great relevance for IPLCs worldwide (CBD, 2016a; UNPFII, 2009). Indeed, both policy instruments explicitly address issues related to IPLCs in some of their targets and goals. For example, Aichi Target 18, under Goal E, is of central importance to IPLCs because it deals directly with traditional knowledge and customary sustainable resource use. It is worth noting, though, that Aichi Target 18 is one of the only Aichi Biodiversity Targets not reflected in the SDGs (see CBD, 2017a). However, there are six direct references to IPLCs in the SDGs, including in SDG 2 related to agricultural output of indigenous small-scale farmers, and SDG 4 on equal access to education for indigenous children. Furthermore, the framework calls on IPLCs to engage actively in implementing the SDGs, including implementation on the national level to ensure that progress for Indigenous Peoples is reflected. However, the indicators used by these policy instruments do not necessarily reflect how progress in achieving goals and targets affect IPLCs, either in positive or in negative ways. This is even more important, as evidence suggest there is a gap between indicators defined in public policies and those that are locally important (Zorondo-Rodriguez *et al*., 2014). Indigenous Peoples have advocated for data disaggregation and the inclusion of an 'indigenous identifier' in official statistics, to capture the inequalities Indigenous Peoples face across all of the SDGs. Moreover, targets and goals scarcely reflect the heterogeneity of IPLCs and how the drivers/conditions described above are manifested in different regions. In this chapter, as well as assessing progress to the Aichi Biodiversity Targets, SDGs, and other MEAs, we report a) the contributions of IPLCs to achieving the goals and targets, and b) how progress (or lack of it) might specifically affect IPLCs.

3.2 PROGRESS TOWARDS THE AICHI BIODIVERSITY TARGETS

3.2.1 Assessment of progress globally

To assess progress towards the Aichi Biodiversity Targets we assembled a broad suite of indicators building on those used by Tittensor *et al*. (2014) and Secretariat of the CBD (2014), which in turn drew on the list of indicators identified by CBD (2012a), and we also utilized relevant additional indicators among those compiled by the Biodiversity Indicators Partnership, the IPBES Knowledge and Data Task Force and other sources. A total of 68 indicators **(Table 3.3)** were selected from more than 160 potential indicators using five criteria: (i) high relevance to a particular Aichi Biodiversity Target and a clear link to the status of biodiversity; (ii) scientific or institutional credibility; (iii) a time series ending after 2010; (or, if the indicator fills a critical gap, the time series ends close to 2010); (iv) at least five annual data points in the time series; and (v) broad geographic (preferably global) coverage. Of these, 30 correspond to the Core Indicators developed for the IPBES regional assessments (see chapter 1 and Supplementary Materials 1.5). Following Tittensor *et al*. (2014), we fitted models to estimate underlying trends using an analysis framework that was adaptive to the variable statistical properties of the indicators. Dynamic linear models (Durbin & Koopman, 2001) were fitted to high-noise time series, while parametric multimode averaging (Burnham & Anderson, 2002) was used for those with low noise. We projected model estimates and confidence intervals to 2020 to estimate trajectories and rates of change for each indicator, scoring each indicator as showing a significant increase, non-significant increase, significant decrease or non-significant decrease. Further details of the methods are provided in the Supplementary Materials.

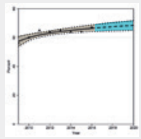
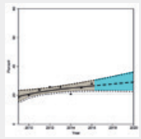
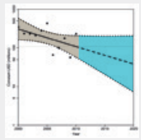
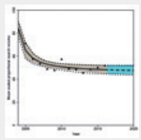
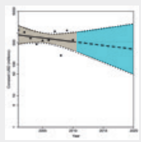
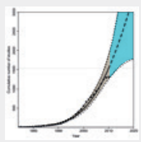
To complement the indicator analysis and to broaden the evidence base for our assessment, we then carried out a systematic review of the literature relevant to each Aichi Biodiversity Target (see Supplementary Materials for details), including on countries' commitments to implement actions by 2020 (e.g., planned protected area designations). We also draw on assessments of progress towards the targets described in countries' National Reports to the CBD (section 3.2.3). We used the full set of evidence to assign a score of progress towards each element of each target and summarize this in **Figure 3.6**. Progress towards each target element was defined as Good (substantial positive trends at a global scale relating to most aspects of the element), Moderate (overall global trend is positive, but insubstantial or insufficient, or there may be substantial positive trends for some aspects of the element, but little or no progress for others, or the trends are positive in some geographic regions but not in others) or Little/no progress or movement away from target (while there may be local/national or case-specific successes and positive trends for some aspects, the overall global trend shows little or negative progress). Where multiple indicators with different trends were available for a particular target element, we gave greater weight to indicators that are of higher alignment (i.e. metrics that relate more directly to the target element rather than indirect proxies), greater geographic coverage, longer time series, and greater relevance to the state of biodiversity that the target aims to address. Where there were no indicators for a particular target element, or only indicators with low alignment and/or low geographic coverage and/or lower relevance to the state of biodiversity that the target aims to address, we used or gave greater weight to the results of the literature review.

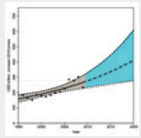
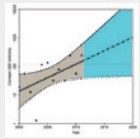
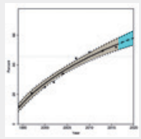
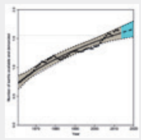
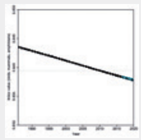
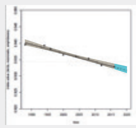
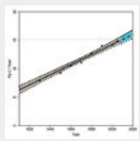
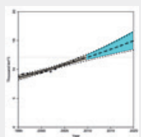
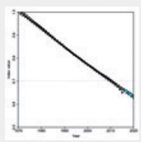
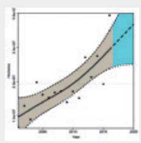
Below, we summarize progress towards each target, drawing on the analysis of indicator extrapolations shown in **Table 3.3** augmented by other available information derived from a literature review. The results are summarized in **Figure 3.6**. We then review the contributions of IPLCs to efforts towards achieving each Aichi Biodiversity Target, and the significance of each target to IPLCs.

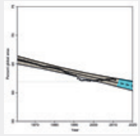
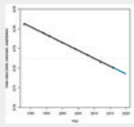
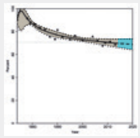
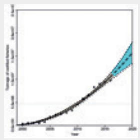
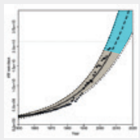
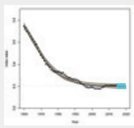
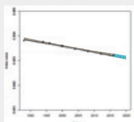
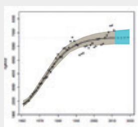
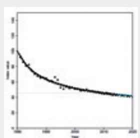
Aichi Target 1: Increasing awareness of biodiversity
Moderate progress has been made towards Aichi Target 1, on increasing awareness of biodiversity and the steps needed to conserve and use it sustainably. The 'biodiversity barometer' shows that knowledge of the values of nature has increased in recent years, at least for a sample of 16 countries with data **(Table 3.3)** but varies substantially (e.g., 40% of people in India have heard of biodiversity, compared with ≥90% in France, Mexico, Brazil, Peru, China and Vietnam; UEBT, 2017). The proportion of people able to correctly define biodiversity shows similarly high variation between countries (e.g., from 1% in India to 72% in Peru; UEBT, 2017). However, people's interest in biodiversity varies over time in relation to economic cycles and other drivers of public interest (Troumbis, 2017). Globally, tourism in National Parks and World Heritage Sites is growing (UNEP-WCMC & IUCN, 2016), and tourism in protected areas helps to raise awareness of the values of biodiversity and provides the opportunity to educate visitors, thereby contributing to this target. Zoos and aquaria can also play a role in raising awareness (Moss *et al*., 2015), as can digital games (Sandbrook *et al*., 2015). Most efforts towards this target have had a local or regional focus, but there are also several global programs to increase awareness of the benefits of nature to people (e.g., www.panorama.solutions, www.bluesolutions.info; www.iucn.org/theme/protected-areas; UNEP-WCMC & IUCN, 2016; Whitehead *et al*., 2014). Global investment in environmental education appears to be decreasing **(Table 3.3)**. In some cases, education has a positive link with the perception

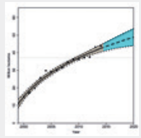
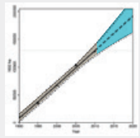
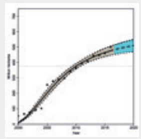
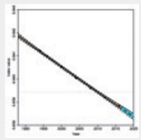
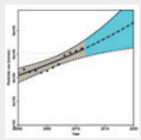
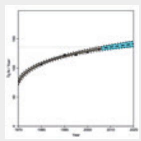
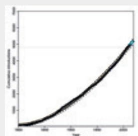
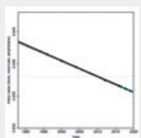
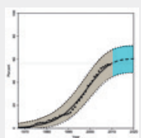
Table 3 3 **Trends of indicators used to assess progress towards the Aichi Biodiversity Targets.**

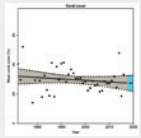
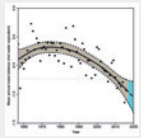
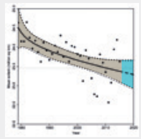
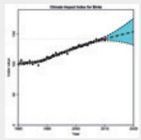
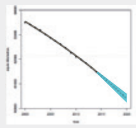
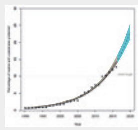
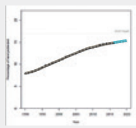
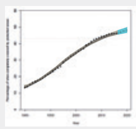
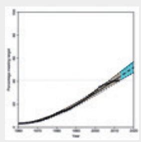
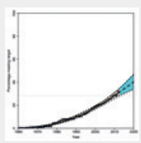
For each element of each of the 20 Targets, relevant indicators are shown along with their alignment to the Target element (i.e. their relevance to the element and the degree to which they are a good proxy, scored as 'low', 'medium', or 'high'), the direction and significance of their projected trend to 2020, and a thumbnail graph (solid line and brown shading show modelled trends with confidence intervals; dotted lines and blue shading shows projected trends with confidence intervals; horizontal line shows 2010 value). Target elements lacking indicators with suitable data for extrapolation are shown in red. Asterisks identify those indicators for which positive trends are generally have negative consequences for biodiversity. Larger format versions of the thumbnail graphs, which include y-axis labels and background information on each indicator, are provided in Table S3.1.2, while the methods to extrapolate and assess the significance of trends to 2020 are provided in the Supplementary Online Materials. The interpretation of the indicator trends in relation to each Aichi Biodiversity Target is given in the text below.

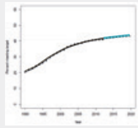
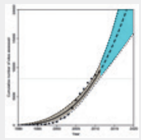
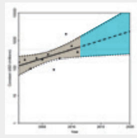
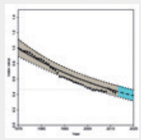
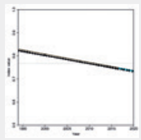
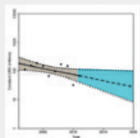
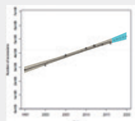
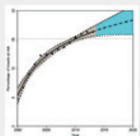
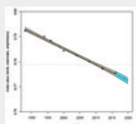
Aichi Target	Target element	Indicator name	Alignment	Projected trend (2010-2020)	Graph
1	**1.1** People are aware of the values of biodiversity	Biodiversity Barometer (% of respondents that have heard of biodiversity)	High	Significant increase	
		Biodiversity Barometer (% of respondents giving correct definition of biodiversity)	High	Significant increase	
		Funding for environmental education ($)	Low	Non-significant decrease	
	1.2 People are aware of […] the steps they can take to conserve and use it sustainably.	Online interest in biodiversity (proportion of google searches)	Medium	Non-significant decrease	
2	**2.1** Biodiversity values have been integrated into national and local development and poverty reduction strategies				
	2.2 Biodiversity values have been […] integrated into national and local planning processes	Funding for Environmental Impact Assessments ($)	Low	Non-significant decrease	
	2.3 Biodiversity values […] are being incorporated into national accounting, as appropriate				
	2.4 Biodiversity values […] are being incorporated into national […] reporting systems	Number of research studies involving economic valuation	Low	Significant increase	
3	**3.1** Incentives, including subsidies, harmful to biodiversity are eliminated, phased out or reformed in order to minimize or avoid negative impacts				

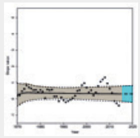
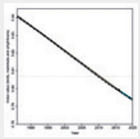
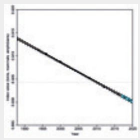
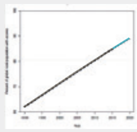
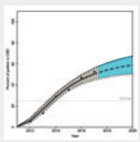
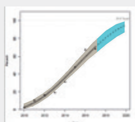
Aichi Target	Target element	Indicator name	Alignment	Projected trend (2010-2020)	Graph
	3.2 Positive incentives for the conservation and sustainable use of biodiversity are developed and applied, consistent and in harmony with the Convention and other relevant international obligations, taking into account national socio economic conditions.	World Trade Organization greenbox agricultural subsidies ($)	Medium	Non-significant increase	
		Funding towards institutional capacity-building in fisheries ($)	Low	Non-significant increase	
	4.1 Governments, business and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption	Percentage of countries that are Category 1 CITES Parties	High	Significant increase	
	4.2 Governments, business and stakeholders at all levels […] have kept the impacts of use of natural resources well within safe ecological limits.	Ecological Footprint (number of earths needed to support human society)*	High	Non-significant increase	
		Red List Index (impacts of utilization)	High	Significant decrease	
		Red List Index (internationally traded species)	Medium	Significant decrease	
		Human appropriation of net primary productivity (Pg C)*	Low	Significant increase	
		Human appropriation of fresh water (water footprint; thousand km^3)*	High	Significant increase	
	5.1 The rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero	Wetland Extent Trends Index	Medium	Significant decrease	
		Area of tree cover loss (ha)*	High	Significant increase	

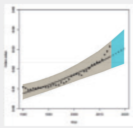
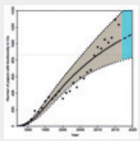
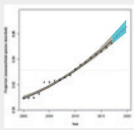
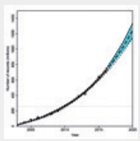
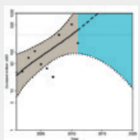
Aichi Target	Target element	Indicator name	Alignment	Projected trend (2010-2020)	Graph
		Percentage natural habitat extent	High	Significant decrease	
	5.2 Degradation and fragmentation [of natural habitats] is significantly reduced	Wild Bird Index (habitat specialists)	Low	Significant decrease	
		Red List index (forest specialists)	Low	Significant decrease	
6	**6.1** All fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, overfishing is avoided [… and] the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits	Proportion of fish stocks within safe biological limits	High	Non-significant decrease	
		Marine Stewardship Council certified fisheries (tonnes)	High	Significant increase	
	6.2 Recovery plans and measures are in place for all depleted species				
	6.3 Fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems	Global effort in bottom-trawling (kW sea-days)*	Medium	Significant increase	
		Marine trophic index	High	Non-significant decrease	
		Red List Index (impacts of fisheries)	Medium	Significant decrease	
7	**7.1** Areas under agriculture […] are managed sustainably	Nitrogen use balance (kg/km^2)	Low	Non-significant increase	
		Wild Bird Index (farmland birds)	Medium	Significant decrease	

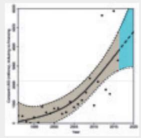
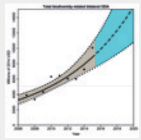
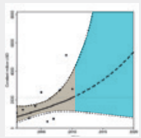
Aichi Target	Target element	Indicator name	Alignment	Projected trend (2010-2020)	Graph
		Area of agricultural land under organic production (million ha)	High	Significant increase	
		Area of agricultural land under conservation agriculture (thosuand ha)	High	Significant increase	
	7.2 Areas under aquaculture […] are managed sustainably				
	7.3 Areas under forestry […] are managed sustainably	Area of forest under FSC and PEFC forest management certification (million ha)	High	Significant increase	
	8.1 Pollution […] has been brought to levels that are not detrimental to ecosystem function and biodiversity.	Red List Index (impacts of pollution)	High	Significant decrease	
		Pesticide use (tonnes)*	Medium	Significant increase	
	8.2 Pollution […] from excess nutrients has been brought to levels that are not detrimental to ecosystem function and biodiversity	Nitrogen surplus (Tg N)*	Medium	Significant increase	
	9.1 Invasive alien species are identified and prioritized	Number of invasive alien species introductions	Medium	Significant increase	
	9.2 [Invasive alien] pathways are identified and prioritized				
	9.3 Priority [invasive] species are controlled or eradicated	Red List Index (impacts of invasive alien species)	Medium	Significant decrease	
	9.4 Measures are in place to manage pathways to prevent their introduction and establishment	Percentage of countries with invasive alien species legislation	High	Non-significant increase	

Aichi Target	Target element	Indicator name	Alignment	Projected trend (2010-2020)	Graph
10	**10.1** The multiple anthropogenic pressures on coral reefs […] are minimized, so as to maintain their integrity and functioning	Percentage live coral cover	High	Non-significant decrease	
	10.2 The multiple anthropogenic pressures on […] other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning	Glacial mass balance (mm water equivalent)	Medium	Significant decrease	
		Mean polar sea ice extent (million km^2)	Medium	Non-significant decrease	
		Climatic Impact Index for birds	Low	Non-significant increase	
		Area of mangrove forest cover (km^2)	Medium	Significant decrease	
11	**11.1** At least 10 per cent of coastal and marine areas […] are conserved	Percentage of marine and coastal areas covered by protected areas	High	Significant increase	
	11.2 At least 17 per cent of terrestrial and inland water areas […] are conserved	Percentage of terrestrial areas covered by protected areas	High	Significant increase	
	11.3 […] Areas of particular importance for biodiversity and ecosystem services, are conserved	Protected area coverage of Key Biodiversity Areas	High	Significant increase	
	11.4 [Areas are conserved through] ecologically representative […] protected areas and other effective area-based conservation measures	Percentage of terrestrial ecoregions covered by protected areas	High	Significant increase	
		Percentage of marine ecoregions covered by protected areas	High	Significant increase	

Aichi Target	Target element	Indicator name	Alignment	Projected trend (2010-2020)	Graph
		Protected area coverage of bird, mammal and amphibian distributions	High	Significant increase	
	11.5 [Areas are conserved through] effectively and equitably managed […] protected areas and other effective area-based conservation measures	Number of protected area management effectiveness assessments	Medium	Significant increase	
		Funding towards nature reserves ($)	Low	Non-significant increase	
	11.6 [Areas are conserved through] well connected systems of protected areas and other effective area-based conservation measures and integrated into the wider landscapes and seascapes				
12	**12.1** The extinction of known threatened species has been prevented				
	12.2 The conservation status [of known threatened species, particularly of those most in decline] has been improved and sustained	Living Planet Index	High	Significant decrease	
		Red List Index	High	Significant decrease	
		Funding towards species protection ($)	Low	Non-significant decrease	
13	**13.1** The genetic diversity of cultivated plants […] is maintained	Number of plant genetic resources for food and agriculture secured in conservation facilities	High	Significant increase	
	13.2 The genetic diversity of […] farmed and domesticated animals […] is maintained	Percentage of terrestrial domesticated animal breeds at risk*	High	Significant increase	
	13.3 The genetic diversity of […] wild relatives […]is maintained	Red List Index (wild relatives of farmed and domesticated species)	High	Significant decrease	

Aichi Target	Target element	Indicator name	Alignment	Projected trend (2010-2020)	Graph
	13.4 The genetic diversity of […] socio-economically as well as culturally valuable species, is maintained				
	13.5 […] Strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity				
14	**14.1** Ecosystems that provide essential services, including services related to water, and contributing to health, livelihoods and well-being, are restored and safeguarded	Percentage change in local species richness	Low	Non-significant	
		Red List Index (species used for food and medicine)	Medium	Significant decrease	
		Red List Index (pollinator species)	Low	Significant decrease	
	14.2 […] Taking into account the needs of women, indigenous and local communities, and the poor and vulnerable	Percentage of global rural population with access to improved water resources	Low	Significant increase	
15	**15.1** Ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration […] thereby contributing to climate change mitigation and adaptation and to combating desertification				
	15.2 […] Including restoration of at least 15 per cent of degraded ecosystems […]				
16	**16.1** The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization is in force [by 2015]	Percentage of countries that have ratified the Nagoya Protocol	High	Significant increase	
	16.2 The Nagoya Protocol […] is operational [and] consistent with national legislation [by 2015]				
17	**17.1** Each Party has developed[…] an effective, participatory and updated national biodiversity strategy and action plan (NBSAP)	Percentage of countries with revised NBSAPs	High	Significant increase	
	17.2 Each Party has […] adopted as a policy instrument […] an effective, participatory and updated national biodiversity strategy and action plan (NBSAP)				

Aichi Target	Target element	Indicator name	Alignment	Projected trend (2010-2020)	Graph
	17.3 Each Party has […] commenced implementing an effective, participatory and updated national biodiversity strategy and action plan (NBSAP)				
	18.1 The traditional knowledge, innovations and practices of indigenous and local communities relevant for the conservation and sustainable use of biodiversity, and their customary use of biological resources, are respected, subject to national legislation and relevant international obligations [...] at all relevant levels.				
	18.2 The traditional knowledge, innovations and practices of indigenous and local communities relevant for the conservation and sustainable use of biodiversity, and their customary use of biological resources, are [...] fully integrated and reflected in the implementation of the Convention [...] at all relevant levels.				
	18.3 The traditional knowledge, innovations and practices of indigenous and local communities relevant for the conservation and sustainable use of biodiversity, and their customary use of biological resources, [are respected, integrated, and reflected] with the full and effective participation of indigenous and local communities, at all relevant levels.				
	19.1 The science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are improved, widely shared and transferred […]	Species Status Information Index	High	Non-significant increase	
		Number of biodiversity papers published	High	Non-significant increase	
		Proportion of known species assessed through the IUCN Red List	High	Significant increase	
		Number of species occurrence records in the Global Biodiversity Information Facility	Low	Significant increase	
		Funding committed to environmental research ($)	Low	Non-significant increase	
	19.2 The science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are […] applied.				

Aichi Target	Target element	Indicator name	Alignment	Projected trend (2010-2020)	Graph
	20.1 The mobilization of financial resources for effectively implementing the Strategic Plan for Biodiversity 2011-2020 from all sources, and in accordance with the consolidated and agreed process in the Strategy for Resource Mobilization, should increase substantially from the current levels [...]	Funding provided by the Global Environment Facility ($)	High	Significant increase	
		Official Development Assistance provided in support of the CBD objectives ($)	High	Significant increase	
		Global funding committed towards environmental policy, laws, regulations and economic instruments ($)	Medium	Non-significant increase	

about biodiversity conservation and the steps needed to conserve and use it sustainably. For example, Vodouhê *et al*. (2010) found that when local communities were trained to participate in park management and gained economic benefits from this, their willingness to engage in biodiversity conservation increased. Similarly, positive messages about marine conservation projects are more effective at motivating conservation actions of the public than messages focusing on the negative impact of their behaviours (Easman *et al*., 2018).

Aichi Target 2: Integrating biodiversity values into development, poverty reduction, planning accounting and reporting

Poor or moderate progress has been achieved towards Aichi Target 2. Some international initiatives have contributed to reducing poverty by supporting natural capital accounting and use of the results in national strategies. According to a report from the International Fund for Agricultural Development (IFAD, a UN specialized agency), it helped to move 24 million people out of poverty during 2010–2015 by transforming agriculture and rural communities, empowering women, improving nutritional status of poor people and building institutions. By strengthening sustainability and resilience in the rural sector and by integrating biodiversity values through sustainable agriculture, IFAD also contributes to the conservation of biodiversity (IFAD, 2016). Investment in environmental impact assessments showed no significant increase since 2010, while no other global indicators are available to assess progress in integrating biodiversity values in national and local planning processes **(Table 3.3)**. The number of scientific publications assessing the economic value of biodiversity increased significantly in recent years **(Table 3.3)**, but few report results from developing economies (Christie *et al*., 2012), and it is unclear to what extent these values are integrated into national accounting and reporting systems (e.g., the Wealth Accounting and Valuation of Ecosystem Services Partnership; WAVES, 2014). One obstacle to incorporating biodiversity values into national accounting and reporting systems is the lack of agreement on what these values are. A tool to facilitate this is the System of Environmental and Economic Accounting (SEEA) adopted by the United Nations Statistical Commission. However, there has been limited integration of this framework into national accounting systems (Vardon *et al*., 2016).

Aichi Target 3: Eliminating harmful incentives and developing and applying positive incentives for biodiversity conservation and sustainable use

There has been poor progress at a global scale towards Aichi Target 3. No global indicators suitable for extrapolation are available to assess progress in eliminating subsidies or other harmful incentives **(Table 3.3)**. In Europe in 2015, significant steps were taken to scale back 'first generation' biofuels, such as rapeseed biodiesel, which have negative consequences for biodiversity because their cultivation in existing agricultural areas displaces food production elsewhere, leading to loss of natural habitats (Oorschot *et al*., 2010; Searchinger *et al*., 2008). Substantial investment in biofuels followed the establishment of EU targets in 2009 in the transport sector for renewables and the de-carbonization of fuels (Valin *et al*., 2015).

There has been poor progress in applying positive incentives for conservation. While agri-environment schemes (in which farmers receive payments to implement biodiversity-friendly agricultural techniques) have been applied in many countries worldwide, and REDD+ schemes have been implemented to reduce greenhouse gas emissions from deforestation and forest degradation, these initiatives are insufficient in scale to deliver substantial progress towards Target 3 (Armsworth *et al*., 2012). Similarly, local approaches to fisheries management, such as cooperatives or individual transferable quotas, often help to improve sustainability, but have been insufficiently implemented (Gelcich *et al*., 2012; Wilen *et al*., 2012). By 2018, only 43 countries had introduced biodiversity-relevant taxes (OECD, 2018).

Aichi Target 4: Implementing plans for sustainable production and consumption

There is a poor progress towards Aichi Target 4. While the proportion of countries that are category 1 signatories to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) has significantly increased, this represents only half of the 183 Parties (CITES, 2018b). This is a very narrow measure in relation to the first part of Aichi Target 4, and unfortunately no other indicators are available to assess progress towards the aim of governments, business and other stakeholders to achieve sustainable production and consumption **(Table 3.3)**, noting that the sustainability of agriculture, aquaculture and forestry specifically are addressed under Aichi Target 7.

The second part of Aichi Target 4 relates to keeping the impacts of the use of natural resources well within safe ecological limits. Progress is being made for several responses aiming to address this **(Table 3.3)**. Growth in human appropriation of net primary production (HANPP) has been slower than human population growth during the twentieth century (Haberl *et al*., 2014), indicating increasingly efficient use of resources. However, projected increases in global population and potential increases in bioenergy use are likely to increase HANPP (Krausmann *et al*., 2013). Similarly, the ecological footprint and water footprint are growing more slowly **(Table 3.3)**. However, species continue to be driven towards extinction through unsustainable use, as shown by a version of the Red List Index showing trends driven by utilization (**Table 3.3**, Butchart, 2008). Demand for greener products and services is increasing and leading to improvements in labeling (Marco *et al*., 2017), but green consumption represents less than 4% of global consumption, and efforts to increase this proportion are needed, particularly in emerging economies (Blok *et al*., 2015). A recent modelling study on internationally traded goods and services concluded that biodiversity loss per citizen is highly variable across countries, but is higher in countries with higher per capita income, with more than 50% of the biodiversity loss associated with consumption in developed economies occurring outside their territorial boundaries (Wilting *et al*., 2017). Two thirds of global biodiversity loss was due to land use and greenhouse emissions, followed by food consumption. However, in rich countries with higher income per capita, consumption of non-food goods and services are the main causes of biodiversity losses (Wilting *et al*., 2017).

Aichi Target 5: Reducing the loss, degradation and fragmentation of natural habitats

The annual rate of net forest loss halved during 1990–2015 according to one assessment (Keenan *et al*., 2015; Morales-Hidalgo *et al*., 2015), but annual tree cover loss derived from globally consistent analysis of remote sensing data increased from 17.2±0.63 million ha/yr in 2001–2010 to 21.3±1.78 million ha/yr in 2011–2016 (globalforestwatch.org; Harris *et al*., 2016). For other natural habitats there is little evidence that rates of loss been brought close to zero, or even halved, indicating that overall, there has been poor or mixed progress towards meeting Aichi Target 5. While there has been growth in the area of land worldwide under timber plantations and afforestation (FAO, 2015a), the former typically do not represent natural habitats, while much of the latter would not yet qualify as forest under stricter definitions (Ahrends *et al*., 2017) and hence are of lower biodiversity significance. Regional assessments in 2016 found that forest loss was continuing across Africa, the Asia-Pacific region (particularly in South-East Asia), and in West Asia, but that there had been significant reduction in rates of forest loss in Latin America and the Caribbean, with mangrove cover increasing in that region (UNEP-WCMC, 2016a, 2016b, 2016c, 2016d). Commercial agriculture is estimated to be the proximate driver for 80% of deforestation worldwide (Kissinger *et al*., 2012), although subsistence agriculture is almost as significant as commercial agriculture in driving deforestation in developing countries (Hosonuma *et al*., 2012), while the key drivers of forest degradation in the tropics include unsustainable logging, fuelwood collection and uncontrolled fires (Kissinger *et al*., 2012). Globally, 27% of global forest loss during 2001–2015 was driven by conversion for commodity production, 26% by forestry, 24% by shifting agriculture and 23% by wildfire (Curtis *et al*., 2018). Despite corporate commitments, the rate of commodity-driven deforestation has not declined (Curtis *et al*., 2018).

The global rate of loss of natural wetlands during the 20th and early 21st centuries averaged 1.085%/yr according to one recent analysis of a sample of wetlands (Davidson *et al*., 2014), while the decline in wetland area averaged 30% during 1970–2008 based on another sampled study (Dixon *et al*., 2016). Permanent surface water was lost from an area of almost 90,000 km^2 between 1984 and 2015, with 70% of this being located in the Middle East and Central Asia, resulting from drought and human actions including damming and diverting rivers and unregulated withdrawal (Pekel *et al*., 2016). While new permanent bodies of surface water covering 184,000 km^2 have formed elsewhere during this period, most are artificial reservoirs (Pekel *et al*., 2016) which are of lower biodiversity significance. Rivers are becoming increasingly fragmented: of the 292 large river systems globally, only 120 (41%) were still free-flowing in 2014, of which 25 (9%) will be fragmented by ongoing or planned construction of dams

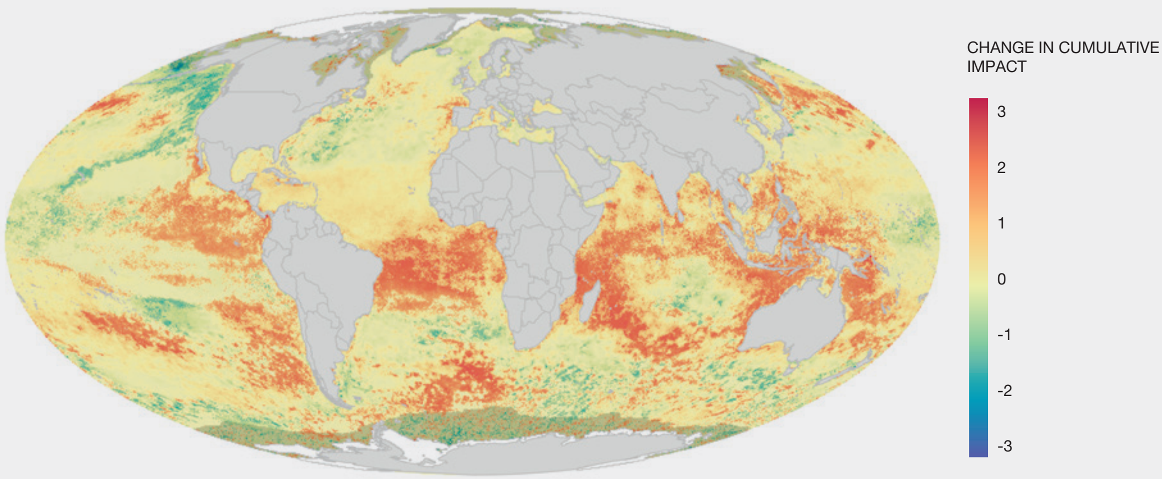


Figure 3 1 **Change in cumulative human impact on marine ecosystems between 2008 and 2013 based on 12 anthropogenic stressors.**

Positive scores represent an increase in cumulative impact; the maximum cumulative impact score for both periods = 11.1. Source: Halpern *et al.* (2015a).

(Nilsson *et al.,* 2005; Zarfl *et al.,* 2014). Reservoirs together with other human activities affect land-ocean sediment and water fluxes, causing impacts on river deltas and loss of coastal habitats (Ericson *et al*., 2006; Syvitski *et al*., 2009; Tessler *et al*., 2015). Overall, an estimated 3.3 million km^2 of wilderness (9.6%) has been lost since the early 1990s, with the most loss occurring in South America (29.6% of wilderness lost) and Africa (14% of wilderness lost) (Watson *et al*., 2016a). Sixty-six per cent of the ocean experienced increases in cumulative human impact during 2008–2013, especially in tropical, subtropical and coastal regions, while only 13% experienced decreases (Halpern *et al*., 2015a; **Figure 3.1**).

Aichi Target 6: Managing and sustainably harvesting aquatic living resources

Overall, we have made poor progress towards meeting Aichi Target 6, with trends in some aspects moving in the opposite direction. World catches increased steadily from the 1950s, peaking between 86 million tonnes (FAO) and 130 million tonnes (Pauly & Zeller, 2016) in 1996. Although trends since have been considered fairly stable by FAO (-0.38 mt.per year), inclusion of other types of catches omitted from FAO data suggests that catches (particularly industrial catches) might be declining significantly (-1.22 mt. per year; Pauly & Zeller, 2016; chapter 5), despite geographic expansion and fishing ever-deeper waters (Maribus, 2013; Pauly & Zeller, 2015). No significant progress has been made on keeping stocks in safe biological limits, while unassessed stocks, mostly in developing countries or small-scale fisheries, are likely to be in substantially worse condition than assessed stocks (Costello *et al*., 2012). Bottom trawling effort is increasing, and the survival probability of marine species is decreasing as a consequence of the impacts of this and other types of fisheries (shown by a version of the Red List Index; **Table 3.3**). Although fishing was rated as the most important anthropogenic driver of biodiversity change in the marine environment (Joppa *et al*., 2016; Knapp *et al*., 2017; Österblom *et al*., 2015), there is no comprehensive global agreement on marine conservation and management (although the United Nations Convention on the Law of the Sea is very relevant, and there are many regional agreements; see **Box 3.1** below). Although the ecosystem approach to fisheries management was proposed in the 1990s to enable more sustainable production, ecosystem drivers of fish stock productivity have rarely been included in management advice (Skern-Mauritze *et al*., 2016). Full biodiversity of stocks is crucial for long-term yields (Worm, 2016). Uncertainties in how climate change will impact the abundance and distribution of fish stocks renders it even more challenging to ensure that harvests are sustainable (Chown *et al*., 2017). Although CBD (2018e) concluded that most countries seem to have taken steps in the right direction to enable sustainable fisheries, in terms of legal, policy and management frameworks, it also projected that at least 30% of fish stocks will be overfished by 2020 under business as usual projections. Recent regional assessments concluded that there is heavy pressure on many fisheries in Africa, sustainable fisheries management is highly variable across Asia-Pacific, there is little information available for West Asia, and there has been poor progress towards sustainability in Latin America and the Caribbean (UNEP-WCMC, 2016a, 2016b, 2016c, 2016d).

The failure of fisheries regulation to prevent overexploitation of fish stocks (Knapp *et al*., 2017) has happened despite the implementation of new legislation and governance systems to enhance protection and management of marine fisheries (Boyes *et al*., 2016; Marchal *et al*., 2016; Vasilakopoulos & Maravelias, 2016), such as the incentivization of illegal, unregulated and unreported fishing in Antarctica by enhancing traceability (through a catch documentation scheme), sanctioning (through an 'illegal unregulated and unreported' vessel blacklist), surveillance (through vessel monitoring systems) and other rules (Abrams *et al*., 2016; CCAMLR, 2016; Chown *et al*., 2017).

The use of market-based instruments such as Marine Stewardship Council certification is increasing **(Table 3.3)**, with about 10% of global wild-caught seafood in some stage of the certification process by March 2015 (MSC, 2015 per Pérez-Ramiréz *et al*., 2016). Co-management between government and local users is increasingly being implemented to achieve more sustainable fisheries (Defeo *et al*., 2016). Many IPLCs have customary sustainable fishery systems that limit harvest levels and impacts to ensure that resources can continue to be used by future generations. Such practices have the potential to contribute to national and international marine biodiversity policies (FPP *et al*., 2016). IPLCs' high reliance on marine ecosystems, including aquatic animals and plants, for food and cultural purposes, results in them being disproportionately affected by unsustainable fishing practices (Cabral & Alino 2011; Cisneros-Montemayor *et al*., 2016), while social responsibility issues in fisheries have only recently began to receive significant attention (Kittinger *et al*., 2017).

CBD (2018e) noted that although there are encouraging signs of reduced pressure on vulnerable seafloor ecosystems, trends in exploitation of sharks and threatened marine fish, and bycatch of seabirds suggest that progress on reducing fisheries pressure on threatened species needs to accelerate. Although there have been some successes in reducing seabird bycatch from long-line and trawl fisheries (e.g., by 90% during 2008–2014 in the South African trawl fishery; BirdLife International, 2016a), seabird bycatch remains an issue in many fisheries, with around 300,000 individuals estimated to die in longline and trawl fisheries each year (Anderson *et al*., 2011), and a further 400,000 in gillnets (Zydelis *et al*., 2013). Bycatch is also major issue for turtles and a number of fish and invertebrate species (Kelleher, 2005).

Since the mid-1990s, total fish production has been increasingly influenced by aquaculture production (**Figure 3.2a**; Granada *et al*., 2016). During 1974–2004, there was a 32% increase in the percentage of fish provided by aquaculture for human consumption (FAO, 2016: 30). However, aquaculture may cause negative environmental impacts including the discharge of effluents and chemical contaminants (antibiotics, parasiticides, metals etc.), the spread of potential invasive species (Granada *et al*., 2016), and increased pressure on other species used as fishmeal. One-sixth of global landings from marine capture fisheries are used to produce fishmeal and fish oil, mainly for aquaculture (Cashion *et al*., 2017; Pauly & Zeller, 2017).

No data are available on the proportion of depleted species with recovery plans and measures in place. CBD (2018e) concluded that although 87% of Parties responding to a survey have plans to allow depleted stocks to recover, specific stock rebuilding plans (that specify not only a rebuilding target but also a deadline for rebuilding with a given probability) are not widely used.

Aichi Target 7: Managing agriculture, aquaculture and forestry sustainably

While some efforts to manage areas under agriculture, aquaculture and forestry sustainably (such as organic agriculture and forestry certification schemes) are increasing, biodiversity in production landscapes continues to decline, meaning that we are moving further away from achieving Aichi Target 7. Regional assessments in 2016 concluded that efforts have been made to improve forestry sustainability in Africa, rates of unsustainable timber harvesting, aquaculture and fisheries are high in Asia, but there has been some (albeit slow) progress in developing schemes for sustainable agriculture, aquaculture and forestry Latin America and Caribbean; all regions lack sufficient data to quantify accurately the trends in sustainability of production systems (UNEP-WCMC, 2016a, 2016b, 2016c, 2016d).

Agricultural expansion is one of the main drivers of global biodiversity loss (Eisner *et al*., 2016; UNCTAD, 2013). In the period 2007–2012, 290,000 km^2 of land were cleared for agriculture, a net increase of 29% compared with 2000–2006. The main drivers of agricultural expansion are global population growth and demand for grain-fed meat (Eisner *et al*., 2016) and production of biofuels (Sachs, 2007). Impacts from unsustainable monoculture-based agriculture with high levels of external inputs include soil degradation and erosion, impoverishment of soil biota (Gianinazzi *et al*., 2010), biodiversity and crop genetic diversity loss, nutrient and water depletion, soil and water contamination, emergence of new pests and diseases (Bubová *et al*., 2015; Reynolds *et al*., 2015; Rusch *et al*., 2016; Thompson *et al*., 2015; UNCTAD, 2013; United Nations Human Rights Council, 2017), and possible ecological risks associated with the use of genetically modified organisms (Wolfenbarger & Phifer, 2000). Simplification of agricultural landscapes through removal of linear habitats and reduction of landscape-scale heterogeneity also impacts farmland biodiversity (e.g., Lee & Martin, 2017). As agricultural land becomes degraded (15–80% is estimated to be currently degraded; Gomiero, 2016), this drives further agricultural

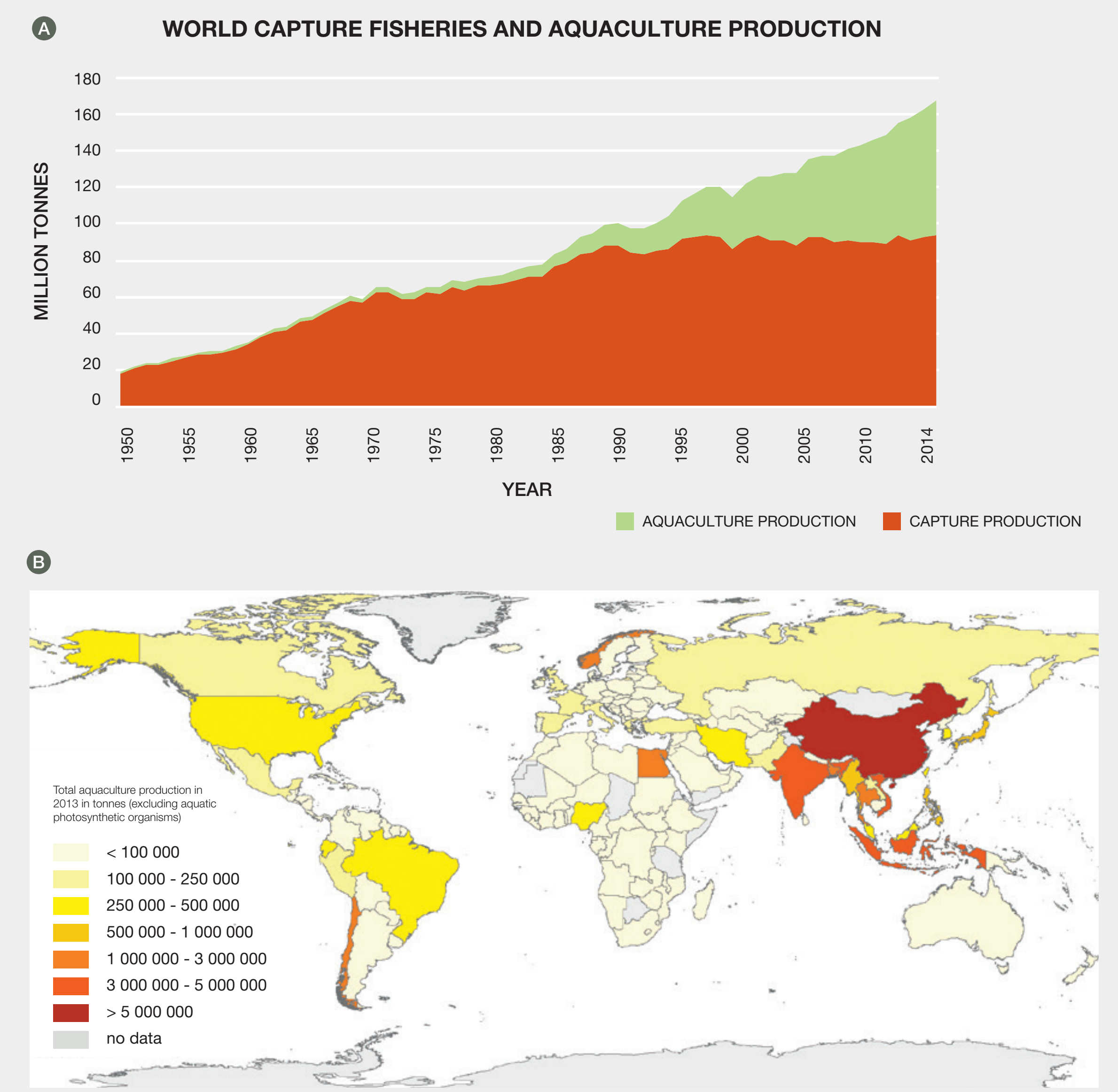


Figure 3 2 **A Global trends in aquaculture production compared with capture fisheries; and B global distribution of aquaculture production in 2013.**

Source for A: FAO (2016a); for B: Ottinger *et al.* (2016: 246).

expansion. While the area of land under organic or conservation agriculture has increased (by 20.7% during 2000–2014), for those regions and taxa with available data, farmland biodiversity continues to decline, as shown by the Wild Bird Index for farmland species **(Table 3.3)**. A global effort has been initiated to enhance biodiversity conservation through the revitalization and sustainable management of "socio-ecological production landscapes and seascapes" (the Satoyama Initiative) (UNU-IAS & IGES, 2015).

While the area under forest certification schemes has increased rapidly (by 37.2% during 2010–2016; **Table 3.3**), much forestry remains unsustainable; local species loss increases from conventional selective logging (13%) and clear-cutting (22%), to timber and fuelwood plantations (40%) (Chaudhary *et al*., 2016). Of all food production systems, aquaculture is the fastest-growing sector worldwide, particularly in South-East Asia **(Figure 3.2b)**, expanding at 8.6% per year during 1983–2013 (FAO, 2014a; Troell *et al*., 2014). Expansion of aquaculture is causing large-scale loss and destruction of coastal wetlands (e.g., mangroves) and pollution of soil and water (Ottinger *et al*., 2015).

Conservation in production landscapes is increasingly recognized as important for maintaining local biodiversity and nature's contributions to people (Ansell *et al.,* 2016; Chaudhary *et al*., 2016; Rusch *et al*., 2016; Thompson *et al*., 2015). Agroforestry systems in Europe enhance biodiversity and the provision of nature's contributions to people compared with forestry and conventional agriculture (Torralba *et al*., 2016). IPLCs' customary sustainable use practices and management systems are increasingly recognized as effective conservation approaches (Berkes *et al*., 2000; Forest Peoples Programme, 2011). For example, protected areas overlapping Indigenous Peoples' territories in Colombia have joint management arrangements for natural and cultural conservation (Leguizamón, 2016). Community-managed forests in the tropics have lower deforestation rates than strict protected areas (Nelson & Chomitz, 2011; Porter-Bolland *et al*., 2012), while traditional management often benefits biodiversity (Cotta *et al*., 2008), and indigenous and traditional shifting cultivation systems create and maintain agrobiodiversity (Carneiro da Cunha & Lima 2017, Padoch & Pinedo-Vasquez, 2010).

Aichi Target 8: Reducing pollution

We have made poor progress towards meeting Aichi Target 8, in particular owing to increasing nitrogen pollution. Global emissions of reactive nitrogen have been increasing rapidly since the 1950s. With the exception of Europe, where nitrogen deposition rates have recently leveled off owing to decreasing emissions since the 1980s, nitrogen deposition is projected to continue to increase globally (Bobbik *et al*., 2010; Shibata *et al*., 2015). Increased reactive nitrogen addition caused by agricultural fertilization or atmospheric deposition to terrestrial ecosystems is considered one of the main drivers of global change (Erisman *et al*., 2013; Galloway *et al*., 2008), while nitrogen accumulation is the main driver of changes in species composition across a wide range of ecosystem types (Bobbik *et al*., 2010; Clark & Tilman, 2008). Nitrogen pollution causes widespread plant biodiversity loss (including through impacts on soil micro-organisms), which can lead to cascading effects (Bobbink *et al*., 2010; Clark & Tilman, 2008; De Schrijver *et al*., 2011; Dupré *et al*., 2010; Shibata *et al*., 2015). Impacts include direct toxicity of nitrogen gases and aerosols, soil-mediated effects of acidification, long-term negative effects of increased ammonia and ammonium availability, eutrophication of aquatic ecosystems, soil and surface water acidification, and reductions in air quality (Bobbink *et al*., 2010; Dupré *et al*., 2010; Phoenix *et al*., 2012; Sponseller *et al*., 2016). Furthermore, nitrogen deposition increases greenhouse emissions from tropical forests, causing a positive feedback to climate change (Cusack *et al*., 2016). Reactive nitrogen pollution also affects human health and has been linked to reduction in drinking water and air quality (Erisman *et al*., 2013). Since 2003, the International Nitrogen Initiative has attempted to improve global nitrogen management (INI, 2017). IPLCs have made important contributions to reductions in nutrient pollution through agricultural practices with little use of chemicals (Altieri & Toledo, 2011; Dublin *et al*., 2014; Wezel *et al*., 2014).

In 2010, severe organic pollution (measured by biochemical oxygen demand) was estimated to affect 6–10% of Latin American, 7–15% of African and 11–17% of Asian river stretches, with levels typically increasing (UNEP, 2016a). No overall progress has been made in minimizing pollution from insecticide use, which continues to grow **(Table 3.3)**. Plastic pollution is increasing in the marine ecosystems (e.g., the western North Atlantic Ocean; Maes *et al*., 2018; Moret-Ferguson *et al*., 2010), and recent estimates are that between 4.8–12.7 million tonnes of plastic waste are entering the oceans every year, between 1.15–2.41 million tonnes carried by rivers (Jambeck *et al*., 2015); effectiveness of plastic bag reduction strategies remains to be evaluated (Xanthos & Walker, 2017). The top 20 rivers feeding into the seas account for 67 per cent of the global total (Lebreton *et al*., 2017; UNEP, 2017). One recent study estimated that there are over 5.25 trillion plastic particles, weighing over 260,000 tons in the world's oceans (Eriksen *et al*., 2014), endangering fish (Romeo *et al*., 2015), seabirds (Croxall *et al*., 2012; Wilcox *et al*., 2015) and other taxa (Baulch & Perry, 2014; Besseling *et al*., 2015; Gall & Thompson, 2015; Wright *et al*., 2013). Coral reefs may be particularly vulnerable, with plastic debris increasing the likelihood of disease by 4–89% (Lamb *et al*., 2018).

These global patterns in pollution trends are mirrored regionally according to recent assessments (UNEP-WCMC, 2016a, 2016b, 2016c, 2016d). In Africa, nutrient pollution is particularly severe in cities and agricultural areas of South Africa and the Nile River. In Asia, nitrogen and phosphorous pollution remains a serious problem, especially deriving from fertilizer use given substantial food demands from the large population in this region. In Latin America and Caribbean, nutrient loading in agricultural areas is also a problem, but pollution is particularly severe in large urban areas, with impacts on downstream rivers and marine areas.

Finally, the negative trend in a version of the Red List Index showing impacts of all types of pollution **(Table 3.3)** indicates that the negative effects of pollution are continuing to drive species towards extinction.

Aichi Target 9: Preventing, control and eradicating invasive alien species

Good progress has been made in identifying, prioritizing and implementing eradications of invasive alien species, with substantial benefits to native species, particularly on islands. However, for most taxonomic groups the numbers of alien species are increasing, suggesting that efforts to mitigate invasions have not been sufficiently effective to match increasing globalization (Seebens *et al*., 2017). Unsurprisingly therefore, invasive alien species are increasingly driving species towards extinction (as shown by the Red List Index, **Table 3.3**), meaning that overall, we are making poor progress towards Aichi Target 9. Comprehensive data on the distribution of invasive alien vertebrates on islands and their impacts on threatened native vertebrates are now available in the *Threatened Island Biodiversity Database* (McCreless *et al*., 2016; Spatz *et al*., 2017). Dataset such as this have allowed systematic prioritization of islands for eradication of invasive species to be completed for some territories, regions or taxa (e.g., Dawson *et al*., 2014; Helmstedt *et al*., 2016; Spatz *et al*., 2014, 2017). Over 800 invasive mammal eradications have been successfully carried out, with estimated benefits through positive demographic and/or distributional responses for at least 596 populations of 236 native terrestrial insular species on 181 islands (Jones *et al*., 2016). More recent data from the *Database on Island Invasive Eradications* (http://diise.islandconservation.org/) indicate that over 85% of the >1,200 eradication attempts to date have been successful. It has been predicted that 107 highly threatened birds, mammals, and reptiles have benefitted from invasive mammal eradications on islands, e.g., island fox *Urocyon littoralis* and Seychelles magpie-robin *Copsychus sechellarum* (Jones *et al*., 2016). Less evidence is available to assess the degree to which measures have been successfully put in place to manage invasion pathways and to prevent the introduction and establishment of invasive alien species. Such efforts are likely to be more cost-effective, but better information is needed to quantify their application and cost-effectiveness. Despite these positive trends, there has been no significant growth in the adoption of national legislation in addressing invasive alien species, the rate of introductions is increasing, and the Red List Index shows that more species have deteriorated in status as a consequence of invasive alien species than have improved in status following successful eradication or control measures **(Table 3.3)**. On continents, there are far fewer examples of successful efforts to manage invasive alien species. In aquatic environments, particularly in the marine realm, more effort is needed to update inventories of invasive alien species and pathways (Tricarico *et al*., 2016). The rate of establishment of alien species appears to be growing across all animal, plant and microbial groups with sufficient information: only mammals and fishes show signs of a slowdown (Seebens *et al*., 2017). Regional assessments reveal a similar pattern, with poor overall progress towards eradicating, controlling and preventing the spread of invasive alien species in Africa, West Asia, Asia-Pacific, Latin America and the Caribbean (UNEP-WCM, 2016a, 2016b, 2016c, 2016d).

Aichi Target 10: Minimising pressures on ecosystems vulnerable to climate change

We have made poor progress on minimizing the multiple anthropogenic pressures on coral reefs and other vulnerable ecosystems impacted by climate change or ocean acidification owing to growing anthropogenic pressures on vulnerable ecosystems and the accelerating impacts of climate change, ocean acidification, and interactions with other threats. This global assessment is reflected at the regional scale too (Jackson *et al*., 2014; UNEP-WCMC, 2016a, 2016b, 2016c, 2016d). More than 60% of the world's coral reefs face immediate direct threats, with overfishing being the most pervasive immediate driver (Burke *et al*., 2011; Mora *et al*., 2016), combined with climate change (Hughes *et al*., 2017a, 2018). Threats to coral reefs increased substantially during 1997–2007, with a 30% increase in the percentage of coral reefs rated as threatened (Burke *et al*., 2011). Corals have shown the steepest declines in status of all groups for which Red List Indices are available **(Figure 3.4b)**. Coral bleaching due to anthropogenic temperature change and ocean acidification affects >90% of coral reefs (Frieler *et al*., 2013), and is becoming more frequent, with further mass-bleaching events in 2015–2017 (Hughes *et al*., 2017a, 2018). Despite these negative trends, the global indicator of percentage of live coral cover showed only a non-significant decline during 1972–2016 **(Table 3.3)**, because individual reef trajectories are hugely variable and only a small proportion of reefs show high or severe mortality (e.g., 10% in the Western Indian Ocean; Obura *et al*., 2017). Given that the pressures on corals are expected to increase in the coming decades, this indicator is expected to decrease significantly in future.

Benthic communities, cold-water corals and seamount communities, among others are also at risk from climate change and ocean acidification (Burke *et al*., 2011; Mora *et al*., 2016; Ramirez-Llodra *et al*., 2011). Responses that have already been observed include hypoxia, distributional shifts, bleaching, and reduced body size, with greater impacts expected owing to synergistic interactions between ocean acidification and warming (Harvey *et al*., 2013; Wilkinson *et al*., 2016). Interactions with other threats, such as eutrophication, pollution, coastal development and overfishing exacerbate the situation (Burke *et al*., 2011, 2016; Mieszkowska *et al*., 2014; Ramirez-Llodra *et al*., 2011). Observed increases in the frequency of outbreaks of seastar *Acanthaster planci* related to nutrient loads have had massive destructive effects (Fabricius *et al*., 2010). Ocean acidification and warming increase the potential for reduction in diversity and abundance of key species in marine ecosystems, and lower ecosystem resilience to future stress (Burke *et al*., 2016; Dupont *et al*.,2010; Nagelkerken & Connell 2015). Plastics have also been recently identified as another major cause of coral reef loss due to light interference, toxin release, physical damage, anoxia and increasing the likelihood of pathogen disease 20-fold (Lamb *et al*., 2018; see also **Box 3.1**).

Climate change impacts on other vulnerable ecosystems, such as mountains and glaciers, including on water storage and run off regulation (Houghton *et al*., 2001), have been widely reported, e.g., Mount Kilimanjaro (Tanzania; UNEP-WCMC 2016a), the Andes (Veettil *et al*., 2017) and in Asia (Kraaijenbrink *et al*., 2017). Polar regions have been particularly affected by climate change and impacts on marine mammals (Laidre *et al*., 2015), birds (Stephens *et al*., 2016), other marine biota (Constable *et al*.,2014), and arctic marine ecosystems in general (Wassmann *et al*., 2013) have been reported. In Antarctica and the Southern Oceans, fisheries and tourism are impacting vulnerable ecosystems (Chown *et al*., 2017). Overfishing, pollution and inappropriate coastal development in coral reef ecosystems are driving declines in diversity and biomass of fish and other organisms, and loss of spatial dominance of corals (Sale 2015). Continental-scale estimates of the magnitude of climate change impacts on species' population trends are available only for birds, for which a Climatic Impact Index shows a growing signal of climate change on population trends since the 1980s across Europe and North America (the only regions with available information; Stephens *et al*., 2016), while other anthropogenic threats continue to drive declines in these species, particularly in farmland habitats (BirdLife International 2018). Climate change impacts on vulnerable ecosystems and species are discussed further under Aichi Target 12: see below.

Aichi Target 11: Conserving terrestrial and marine areas through protected areas and other area-based measures

While the world's protected area network continues to expand and may exceed numerical targets for coverage of terrestrial and marine environments by 2020, there has been only moderate progress towards other aspects of Aichi Target 11 in both the terrestrial and marine environment. This pattern is reflected regionally too (UNEP-WCMC, 2016a, 2016b, 2016c, 2016d). By September 2018, the *World Database on Protected Areas* showed that 14.9% of the world's terrestrial and freshwater environments was covered by protected areas, with 7.44% of the marine realm area covered (17.2% of marine areas within national jurisdiction, and 1.18% of marine areas beyond national jurisdiction (Gannon *et al*., 2017; UNEP-WCMC & IUCN, 2018). In Antarctica, <4% of the ice-free terrestrial area is protected (Chown *et al*., 2017). Specific commitments made by particular countries for new/expanded protected areas through National Priority Actions, National Biodiversity Strategies and Action Plans or projects from the fifth and sixth replenishment of the Global Environment Facility total over 3.9 million km^2 on land and over 13 million km^2 in the oceans (CBD, 2018b). If these are fulfilled before 2020, coverage is expected to exceed 10% of the global ocean and 17% of terrestrial and inland water (**Figure 3.3a**; CBD, 2018b).

Recent growth in the global protected area network has been greatest in the marine environment, with the coverage of marine protected areas increasing from 2 million km^2 (0.7% of the ocean) in 2000 to 26.9 million km^2 (7.44%) at present. This increase has resulted in particular from the establishment of some extremely large marine protected areas (Gannon *et al*.,2017; Thomas *et al*., 2014), such as the Marae Moana Marine Park in the Cook Islands in 2017 (1.97 million km^2) and the expansion in 2016 of the Papahānaumokuākea Marine National Monument in the Hawaiian Islands (1.5 million km^2), representing the second and fourth largest marine protected areas worldwide respectively. The establishment of marine protected areas in Areas Beyond National Jurisdiction has mostly been driven by the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) and the Convention for the Conservation of Antarctic Marine Living Resources (CCMALR) (UNEP-WCMC & IUCN, 2016). Protection of biodiversity in the high seas has considerable governance challenges. The organizations with the authority to protect and manage the marine resources in the high seas are: (1) the International Maritime Organization, which can designate Particularly Sensitive Sea Areas to control shipping activities, (2) the International Seabed Authority, which can designate Areas of Particular Interest to control deep seabed mining, and (3) the Regional Fisheries Management Organizations, which can designate closure for certain fisheries or protect Vulnerable Marine Ecosystems as defined by the UN (Wright *et al*., 2016), but protection of the high seas is still uneven and cooperation is weak across the existing agreements (Ardron & Warner, 2015; Ardron *et al*., 2014). In response, two major initiatives are underway to strengthen conservation of the marine environment, in particular through establishment of marine protected areas in the high seas. The CBD has developed criteria and processes to describe Ecologically or Biologically Significant Areas (EBSAs) to support national and international management of ocean habitats and resources (Dunn *et al*., 2014; Dunstan *et al*., 2016), 279 of which have been described to date (Bax *et al*., 2016; CBD, 2017b). The second initiative has been driven by the United Nations General Assembly, with countries agreeing in 2015 to open negotiations for a new legally binding instrument on the conservation and sustainable use of marine biodiversity in Areas Beyond National Jurisdiction under the United Nations Convention on the Law of the Sea (Rochette *et al*., 2015; Wright *et al*., 2013, 2016).

The extent and distribution of 'other effective area-based conservation measures' (OECMs, as referred to in Aichi Target 11, such as some privately managed areas and territories and areas managed by Indigenous Peoples and Local Communities) is not well documented (Gannon *et al*., 2017; UNEP-WCMC & IUCN, 2016). This is partly because a definition of such areas has only recently been developed (CBD, 2018h). Once documented, inclusion of such areas will likely also substantially increase the estimates above of terrestrial and marine coverage by protected areas and conserved areas. The contribution of IPLCs to protected area growth, and the impact of this on IPLCs, is discussed in greater detail in section 3.2.4.

Moderate progress has been made towards ecological representativeness, effective management and protection of areas of importance for biodiversity. Although ecological representation of protected area networks has increased (Kuempel *et al*., 2016), by April 2018, only 43.4% of the world's 823 terrestrial ecoregions have at least 17% of their area covered by protected areas and 42.7% of the 232 marine ecoregions (and 10.8% of pelagic provinces) have at least 10% of their area covered (CBD, 2018b; EC-JRC, 2018). One quarter of terrestrial ecoregions (207, 24%) have been identified as 'imperiled', where the area of protected and unprotected natural habitat remaining is less than or equal to 20% (and averages only 4%) (Dinerstein *et al*., 2017). Protected area coverage of species distributions also remains insufficient (Goettsch *et al*., 2018; Venter *et al*., 2017), and over half (57%) of 25,380 species assessed to date have inadequate coverage of their distributions by protected areas (Butchart *et al*., 2015). Recent protected area expansion has failed to target places with high concentration of threatened vertebrate species: if protected area growth during 2004–2014 had strategically targeted unrepresented threatened vertebrates, it would have been feasible to protect over 30 times more threatened species for the same area or cost as the actual expansion that occurred (Venter *et al*., 2017).

Only 20.7% of Key Biodiversity Areas ('sites contributing significantly to the global persistence of biodiversity') are completely covered by protected areas (BirdLife International *et al*., 2018; Butchart *et al*., 2012, 2016). The global mean percentage area of terrestrial Key Biodiversity Areas covered by protected areas increased from 35.0% in 2000 to 46.6% in 2018, with the equivalent figures being 31.9% to 43.5% for freshwater Key Biodiversity Areas and 31.7% to 44.3% for marine Key Biodiversity Areas (**Figure 3.3b**; BirdLife International *et al*., 2018). Of the protected areas that overlap Key Biodiversity Areas and that have data available on governance, just 1.01% are managed by Indigenous Peoples and Local Communities, or are nationally designated as indigenous, local, or community lands, covering 2.37% of the overlapping area (based on spatial analysis of data from BirdLife International, 2016b and IUCN & UNEP-WCMC, 2016). A significant but unknown proportion of Key Biodiversity Areas are also likely to be covered by OECMs (BirdLife International, 2014). Recent protected area expansion has disproportionately targeted area outside Key Biodiversity Areas (Butchart *et al*., 2012), meaning that insufficient attention is being paid to the element of Aichi Target 11 addressing 'areas of particular importance for biodiversity'.

Currently, there is no global indicator measuring the extent to which areas of importance for ecosystem services are protected or the effectiveness of such protection (Spalding *et al*., 2014), while national studies typically show a mismatch between the distribution of protected areas and locations of importance for ecosystem services (e.g., protected areas cover 15.1% of China's terrestrial surface, but only 10.2–12.5% of the source areas for four key regulating services; Xu *et al*., 2017). Similarly, there is a mismatch between marine protected areas and locations of importance for ecosystem services (Lindegren *et al*., 2018).

Although there are positive trends in the number of protected areas with assessments of management effectiveness **(Table 3.3)**, as of May 2018, only 21% of countries have assessed management effectiveness for at least 60% of their terrestrial protected areas (and 16% of countries had done so for at least 60% of their marine protected areas): the target under the CBD Programme of Work on Protected Areas (CBD, 2010b; Coad *et al*., 2015; UNEP-WCMC, 2018b). The *Atlas of Marine Protection* (an independent attempt to track the adequacy of protection of marine protected areas) estimates that as little as 3.6% of the global ocean is covered by fully implemented and actively managed protected areas (Marine Conservation Institute, 2017). In many countries, less than half of protected areas are effectively managed, having the same level of modification as non-protected lands (Clark *et al*., 2013), while only 10% of protected areas are free from human pressure (Jones *et al*., 2018). A main driver of ineffectiveness is the unsustainable use of biological resources (Shulze *et al*., 2018), while some protected areas may be too small to conserve the target species they aim to protect (Mallari *et al*., 2016). Without a comprehensive global dataset on protected area management effectiveness, it is difficult to estimate what percentage of the terrestrial/freshwater and ocean environments is effectively protected, but it is likely to fall far short of the percentages for absolute coverage reported above. One recent assessment found that only 21% of a sample of marine protected areas met more than half of nine thresholds for effective management, although 71% of marine protected areas showed positive responses in fish biomass, which averaged 1.6 times higher than in matched unprotected areas (Gill *et al*., 2017). There is significant evidence, especially from "no-take" marine reserves, that protecting marine biodiversity and ecosystems delivers benefits (e.g., Aburto-Oropeza *et al*., 2011; Mellin *et al*., 2016). A recent meta-analysis found that most studies showed that protected areas helped to reduce declines in both species' populations (74% of 42 relevant counterfactual studies) and habitat (79% of 60 studies) (Geldmann *et al*., 2013). Similarly, analysis of studies of biodiversity responses to land-use change found that protected areas were effective at retaining species richness and local abundance (Gray *et al*., 2016).

No agreed methodology exists for tracking progress towards equitable management of protected areas (Corrigan *et al*., 2017; Spalding *et al*., 2014), although indicators

(Zafra-Calvo *et al*., 2017) and frameworks have been proposed (Schreckenberg *et al*., 2016). The proportion of sites in the *World Database on Protected Areas* reporting shared governance increased from 1.8% in 2016 to 3.3% in 2018 (CBD, 2018b). Protected areas that explicitly integrated local stakeholders are significantly more effective at achieving conservation and socioeconomic outcomes (Oldekop *et al*., 2016), but data on protected area socio-ecological effects are generally lacking (Pendleton *et al*., 2017).

Adequately connected protected areas cover only 9.3–11.7% of the terrestrial realm, with only about a third of the world's ecoregions and 30.5% of countries currently having 17% of their area covered by well-connected protected areas, indicating that the spatial arrangement of protected areas is only partially successful in ensuring connectivity of protected lands (Santini *et al*., 2016; Saura *et al*., 2017, 2018). Connectivity of marine protected areas has not yet been assessed (Gannon *et al*., 2017). Protected area management strategies would be more effective if they took greater consideration of connectivity (particularly in freshwater ecosystems), contextual vulnerability, and required human and technical capacity (Juffe-Bignoli *et al*., 2016b), and were better embedded within integrated spatial planning. While uptake of the latter appears to be accelerating in the marine realm, only c.10% of jurisdictional waters are currently under some level of marine spatial planning (Spalding *et al*., 2014).

Finally, few protected areas are currently taking into account climate change in their management (Poiani *et al*., 2010), but the effects of climate change on protected areas will be profound (e.g., Araujo *et al*., 2011; Bagchi *et al*., 2012; Baker *et al*., 2015; Hole *et al*., 2009; Zomer *et al*., 2015), and addressing them will require the development and implementation of coherent, network-scale, adaptation plans (Dudley *et al*., 2010; Hole *et al*., 2011; Wiens *et al*., 2011). This is particularly important given that effectively managed protected areas can help to buffer the negative impacts of climate change, reduce disaster risks, and contribute to climate change mitigation and adaptation (Hole *et al*., 2011; Lawson *et al*., 2014; Nogueira *et al*., 2018; Virkkala *et al*., 2014).

Aichi Target 12: Preventing extinctions and improving the conservation status of species

Poor progress has been made overall towards Aichi Target 12, although trends would have been worse in the absence of conservation action. A total of 25,062 species are listed as threatened on the IUCN Red List, the global standard for assessing extinction risk (IUCN, 2017). It is important to note, however, that only 87,967 species have been assessed for the Red List, with 95% of described species not yet evaluated (IUCN, 2017). Best estimates (with upper and lower bounds) of the proportion of species threatened with extinction average 23.7% (20–34%) across comprehensively assessed taxonomic groups, ranging from 7% (7–18%) for selected families of bony fishes, to 13% (13–14%) of birds, 25% (22–36%) of mammals, 31% (18–60%) of sharks and rays, 33% (27–44%) of reef-forming corals, 34% (34–35%) of conifers, 36% (32-44%) of selected families of dicots (magnolias and cacti), 41% (32–55%) of amphibians, and 63% (63-64%) of cycads (**Figure 3.4a;** IUCN, 2017). Among those groups in which not all species have yet been assessed, a sampling approach suggests that the proportion of species that are threatened ranges from 14% (9–44%) for dragonflies and damselflies (Clausnitzer *et al*., 2009) to 19% (15–36%) for reptiles (Böhm *et al*., 2013) and 22% (20–26%) for plants (Brummitt *et al*., 2015). Considering phylogenetic diversity together with extinction risk elevates the conservation priority of many mammal and bird species (Isaac *et al*., 2007; Jetz *et al*., 2014; Safi *et al*., 2013).

Concentrations of threatened species occur in South-East Asia, the Andes, the Caribbean, Madagascar, New Zealand, and other oceanic islands (IUCN, 2009; Pereira *et al*., 2012). Primary threats to threatened species are unsustainable agriculture, biological resource use, invasive species, land use, and residential and commercial development (Joppa *et al*., 2016). Recent extinctions include Bramble Cay melomys *Melomys rubicola* in Australia (last seen in 2007, declared extinct in 2016; Gynther *et al*., 2016; Woinarski & Burbidge, 2016; Woinarski *et al*., 2014), Western black rhinoceros *Diceros bicornis longipes* in Cameroon (last reported in 2006, declared extinct in 2011; Emslie, 2012), Javan rhinoceros *Rhinoceros sondaicus annamiticus* in Vietnam in 2011 (Kinver, 2011), the Pinta Giant Tortoise *Chelonoidis abingdonii* in Galapagos in 2012 (Cayot *et al*., 2016) and the Alagoas Foliage-gleaner *Philydor novaesi* in 2011 (Lees *et al*., 2014; Butchart *et al*., 2018). However, extinctions per se are extremely difficult to detect (Butchart *et al*., 2006, 2018), so a more useful metric of relevance is the Red List Index, which shows that, overall, species are continuing to move towards extinction rapidly, with cycads, amphibians and particularly corals declining most rapidly **(Figure 3.4b)**. This global trend is repeated across all regions (UNEP-WCMC, 2016a, 2016b, 2016c, 2016d). Among carnivores and ungulates, one quarter of all species moved one or more categories closer to extinction globally since the 1970s. For each species that improved in status (towards less threatened categories), eight species deteriorated in status during this period (Di Marco *et al*., 2014). Rodrigues *et al*. (2014) found that 50% of the global deterioration in the extinction risk status of vertebrates is concentrated in 1% of the surface area, 39/1,098 ecoregions (4%) and 8/195 countries (4%): Australia, China, Colombia, Ecuador, Indonesia, Malaysia, Mexico, and the United States.

It is notable that extinction risk trends would have been worse in the absence of conservation: for birds,

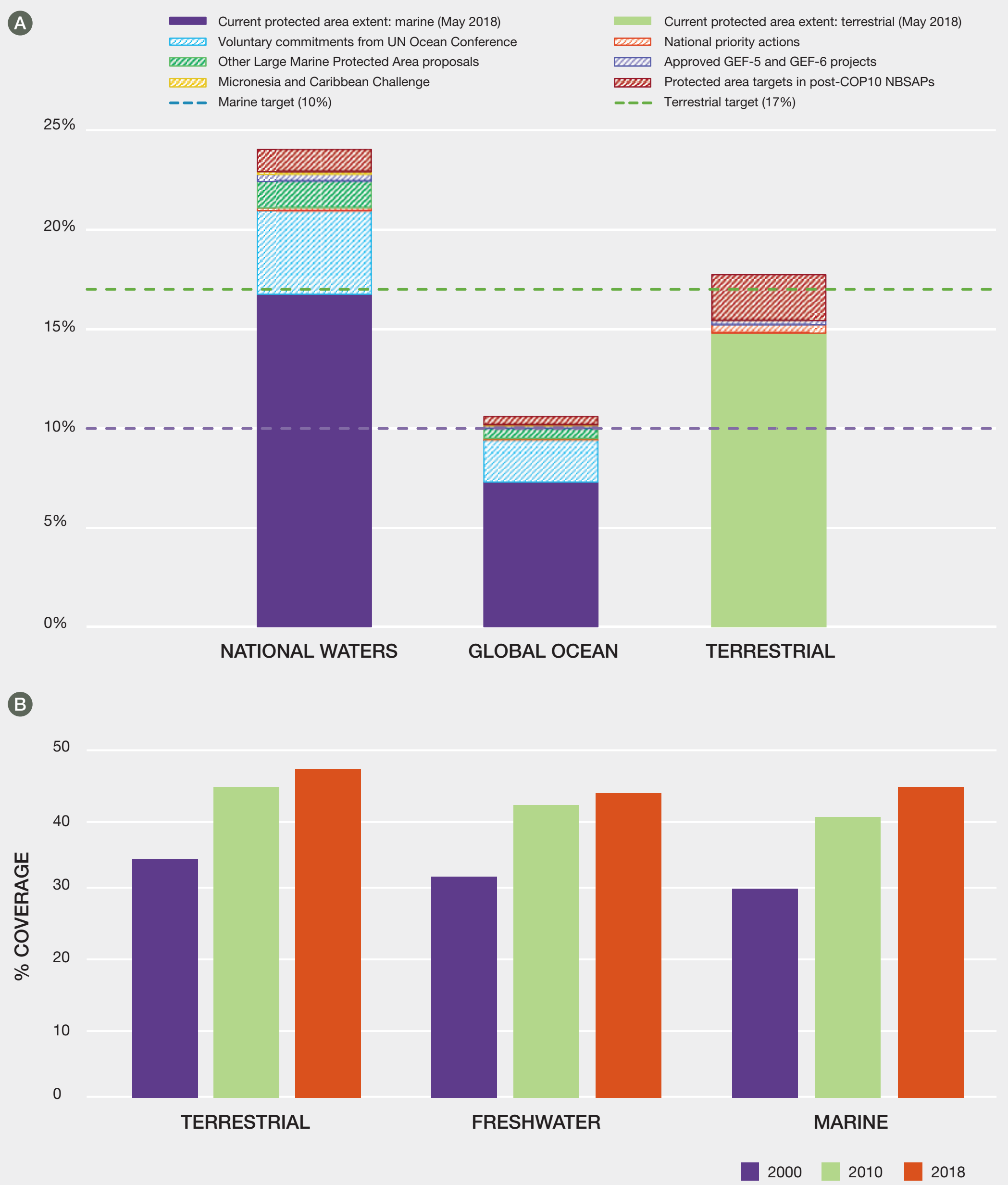


Figure 3 3 **Progress towards elements of Aichi Target 11.**

A Current and projected coverage of marine and terrestrial areas by protected areas, showing the potential contributions of approved projects through 5th and 6th replenishments of the Global Environment Facility (GEF-5 and GEF-6), national targets defined in National Biodiversity Strategies and Action Plans, and other national commitments, in addition to coverage documented in the May 2018 release of the *World Database on Protected Areas* (dotted lines indicate the thresholds of 10% of coastal and marine areas and 17% of terrestrial and freshwater areas, as specified in Target 11); B Increase in mean percentage of Key Biodiversity Areas covered by protected areas in different ecosystems. Source for A CBD (2018b); for B BirdLife International, IUCN and UNEP-WCMC (2018).

conservation action reduced the decline in the Red List Index equivalent to preventing 39 species (2.8% of threatened species) each moving one IUCN Red List category closer to extinction between 1988 and 2008, while for mammals the figures were equivalent to preventing 29 species (2.4% of threatened species) moving one category closer to extinction between 1996 and 2008 (Hoffmann *et al*., 2010). A subsequent analysis focusing on ungulates estimated that without conservation, at least 148 species would have deteriorated by one IUCN Red List category during 1996-2008, including six species that now would be listed as extinct (Javan Rhinoceros *Rhinoceros sondaicus*, Greater One-horned Rhinoceros *R. unicornis* and Kouprey *Bos sauveli*) or extinct in the wild (Arabian

Oryx *Oryx leucoryx*, Przewalski's Horse *Equus ferus* and Bawean Deer *Axis kuhlii*). For birds, 16 species would have gone extinct during 1994–2004 without conservation action, and another 10 species would have gone extinct prior to 1994 without conservation action (Butchart *et al*., 2006). The overall decline in the status of ungulates would have been nearly eight times worse than observed without conservation efforts (Hoffmann *et al*., 2015). A recent model estimated that conservation investment during 1996–2008 reduced biodiversity loss (measured in terms of changes in extinction risk for mammals and bird) in 109 countries by 29% per country on average (Waldron *et al*., 2017). Finally, a recent analysis concluded that five species of pheasants and partridges in Sundaland (the Malay Peninsula to Bali) survive only in protected areas and have been entirely extirpated in unprotected areas (Boakes *et al*., 2018). These studies provide rare comparisons of how trends in the state of nature would have been different in the absence of conservation efforts.

From 1970 to 2012, global populations of vertebrate species declined by 58% (48–66%), on average, according to the Living Planet Index. Overall declines were higher in the freshwater realm (81%; 68–89%) than the terrestrial (38%; 21–51%) and marine realms (36%; 20–48%) (McRae *et al*., 2017; WWF, 2016). In a sample of 27,600 vertebrate species, 32% were found to be decreasing in population size and range, while for 177 mammals with detailed data, all have lost more than 30% of their range, and over 40% have lost over 80% of their range (Ceballos *et al*., 2017).

Insufficient data are available to assess trends in genetic diversity (Pereira *et al*., 2012). Protected areas have a key role in conserving threatened species but while the total extent of protected areas has grown, many important sites for threatened species (Key Biodiversity Areas) remain unprotected (see above). For the subset of Key Biodiversity Areas that qualify as Alliance for Zero Extinction sites (because they hold effectively the entire global population of at least one Critically Endangered or Endangered species), the global mean percentage area of these sites covered by protected areas increased from 33.4% in 2000 to 42.6% in 2017.

Progress towards Aichi Target 12 is being hampered by the increasing impacts of climate change, which is exacerbating the challenge of conserving species. Most ecological processes (82%) in marine, terrestrial and freshwater environments that underpin ecosystem functioning and support services to people now show evidence of impact from climate change (Poloczanska *et al*., 2016; Scheffers *et al*., 2016; Settele *et al*., 2014). Examples of observed impacts include shifts in species ranges, changes in phenology, altered population dynamics, and other disruptions scaling from genes to ecosystems (BirdLife International & National Audubon Society, 2015; Poloczanska *et al*., 2016; Scheffers *et al*., 2016). For example, in North American temperate forests, surges in mountain pine beetle infestations are associated with warmer temperatures, particularly in winter (Creedon *et al*., 2014), with resulting effects on survival of species such as the Whitebark Pine *Pinus albicaulis* and Grizzly Bear *Ursus arctos* in Yellowstone National Park (Saunders *et al*., 2009). Warming temperatures in Hawaii are leading to invasive mosquitoes and introduced disease spreading to higher elevations, driving rapid declines in in the populations of many native bird species (Benning *et al*., 2002; Paxton *et al*., 2016). European butterfly communities shifted an average of 114 km northwards during 1990–2008 (Devictor *et al*., 2012), while timing mismatches have been observed between butterflies and their host plants (Parmesan *et al*., 2013). Mass-bleaching of coral reefs has become a recurrent occurrence, ocurring most recently in 2015–2016 (Hughes *et al*., 2017a). In the Arctic, marine species are under threat from changes in their physical, chemical and biological environment, with a number of species shifting their ranges northwards to seek more favourable conditions as the Arctic warms (particularly mobile open-water species such as Polar Cod *Arctogadus glacialis*; CAFF, 2013) (see **Box 3.2**). Almost half (47%) of terrestrial non-volant threatened mammals and 23.4% of threatened birds may have already been negatively impacted by climate change in at least part of their distribution (Pacifici *et al*., 2017), while strong evidence suggests that bird populations in North America and Europe have been affected by climate change since the 1980s, with 'warm'-adapted species increasing in abundance, and 'cold'-adapted species either stable or declining in abundance (Stephens *et al*., 2016). One recent assessment of 987 populations of 481 terrestrial bird and mammal species found that declines in population abundance since 1950 were greater in areas where mean temperature has increased more rapidly, and that this effect was more pronounced for birds (Spooner *et al*., 2018).

Projected impacts suggest that climate change will greatly increase the number of species under threat, with most studies on birds concluding that there are likely to be fewer species that expand their ranges or experience more suitable conditions than the number that experience range contraction or less suitable conditions (BirdLife International & National Audubon Society, 2015). Large-scale redistribution of fish populations is also predicted (with consequences for fisheries too; Cheung *et al*., 2010). Species reliant on sea ice for reproduction, resting or foraging will experience range reductions if current trends continue (CAFF, 2017).

Other factors that hamper progress towards Aichi Target 12 include insufficient holistic species conservation planning, with inadequate consideration given to socioeconomic aspects, monitoring and evaluation (Mair *et al*., 2018).

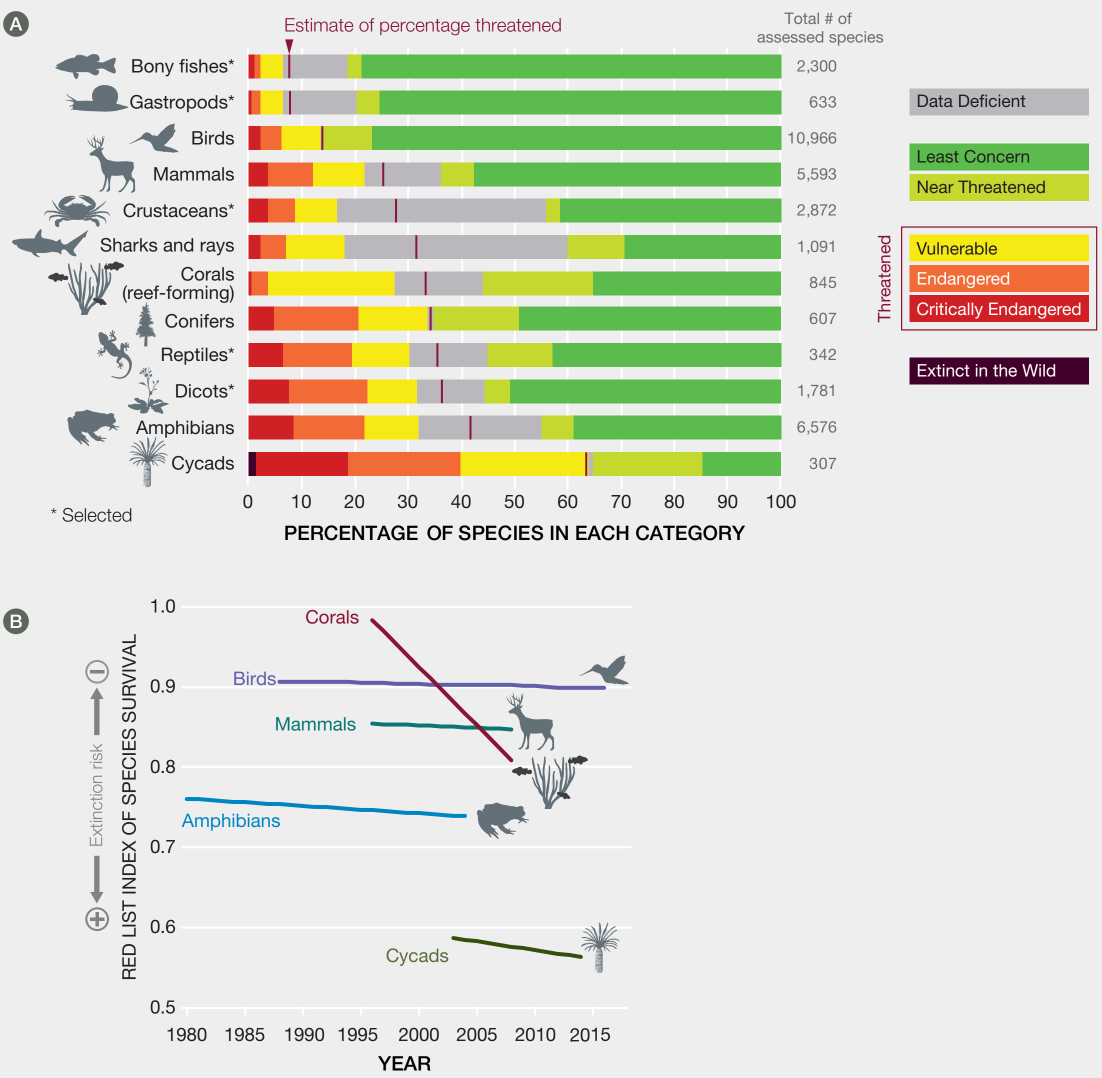


Figure 3 4 **A substantial proportion of assessed species are threatened with extinction and overall trends are deteriorating, with extinction rates increasing sharply in the past century.**

A Percentage of species threatened with extinction in taxonomic groups that have been assessed comprehensively, or through a 'sampled' approach, or for which selected subsets have been assessed, by the International Union for Conservation of Nature (IUCN) Red List of Threatened Species. Species in are grouped into classes (with the exception of reef-forming corals, which includes species from classes Hydrozoa and Anthozoa). Groups are ordered according to the best estimate for the percentage of extant species considered threatened (shown by the vertical blue lines), assuming that data deficient species are as threatened as non-data deficient species. For 'sampled' and 'selected' groups, the total estimated number of described specie are as follows: bony fishes: 28,000, gastropods: 85,000, dragonflies: 3,000, ferns and relatives: 12,000, monocots: 60,000, reptiles: 10,793, crustaceans: 47,000, dicots: 208,000. The taxonomic subsets included in the 'selected' groups are listed at http://www.iucnredlist.org/about/summary-statistics. B Red List Index of species survival for taxonomic groups that have been assessed for the IUCN Red List at least twice. A value of 1 is equivalent to all species being categorized as Least Concern; a value of zero is equivalent to all species being classified as Extinct.
Data for both panels derive from www.iucnredlist.org, plus Butchart *et al.* (2016) for panel B.

Aichi Target 13: Maintaining genetic diversity

We are far from maintaining and safeguarding the genetic diversity of cultivated plants, farmed and domesticated animals, and wild relatives, and hence meeting Aichi Target 13. While many varieties of crops and domesticated animals are held in gene banks (FAO 2015c), overall genetic diversity is being eroded, and renewed approaches to the management and research on domesticated biodiversity is needed (Carvalho *et al*., 2012; Newton *et al*., 2010), particularly given the threat of climate change (Mercer & Perales, 2010). Recent initiatives are pursuing more efficient and effective conservation strategies for *ex situ* crop conservation (Khoury *et al*., 2010), but the diversity of crop wild relatives is still poorly represented: 29.1% of taxa have no germplasm accession and 23.9% are represented with fewer than ten accessions (Castañeda-Álvarez *et al*., 2016). Furthermore, 95% of taxa have insufficient representation of the geographic and ecological variation across their native ranges, with significant gaps in the Mediterranean and the Near East, Western and Southern Europe, Southeast and East Asia, and South America (Castañeda-Álvarez *et al*., 2016).

Progress towards achieving this target has been hampered by the absence of relevant inventories of crop diversity (including major and minor cereals, root and tuber crops, oil crops, vegetables, fruits, fodder and spices), declines in the cultivation of many varieties, and the absence of national institutions responsible for their conservation (Castañeda-Álvarez *et al*., 2016; Newton *et al*., 2010). Genetic pollution i.e., contamination by gene flow from conventional and biotechnologically bred crops and introduced alien species threaten cereal varieties (Carvalho *et al*., 2012), but poor progress has been made in minimizing and mitigating this threat. For non-commercial and local breed livestock there is still a paucity of indicators of genetic erosion and diversity (Bruford *et al*., 2015). The proportion of domesticated breeds categorized as at risk or extinct is increasing **(Table 3.3)**, indicating a decline in livestock diversity, but the rate of increase is slowing, potentially suggesting that countries are making some progress in safeguarding domesticated animals. The extinction risk of wild relatives of domesticated or farmed birds and mammals is increasing, as shown by declining Red List Index trends, suggesting that potentially valuable genetic diversity is being lost (McGowan *et al*., 2018). Regional assessments of progress towards this target found that trends in genetic diversity are unknown in Asia, while progress has been poor in Africa, Latin America and the Caribbean (UNEP-WCMC, 2016a, 2016b, 2016c, 2016d).

Aichi Target 14: Restoring and safeguarding ecosystems that provide essential services

Poor progress has been made towards achieving Aichi Target 14. An analysis of 21 indicators of the state of nature and 13 indicators of nature's contributions to people showed that while 60% of the latter indicators have positive trends, 86% of indicators of the state of nature show declines (Shepherd *et al*., 2016). This suggests that while good quality of life is increasing in the short-term, it is based on unsustainable use of nature. As soil fertility continues to decline, it is doubtful that good quality of life can continue to increase without negative impacts on nature's contributions to people (Shepherd *et al*., 2016).

Mangroves are a good example of an ecosystem that contribute to good quality of life, providing food and feed (including through sustaining fisheries), energy (fuelwood), materials (wood for construction), medicinal resources, regulation of coastal water quality, regulation of hazards (coastal protection), physical and psychological experiences (nature-based tourism), regulation of climate (carbon sequestration), and supporting identities (cultural services), among others (e.g., Datta *et al*., 2012). About 38% of the global extent of mangroves had been lost by 2010 (Thomas *et al*., 2017), but there has been no comprehensive assessment of trends in their global extent, and hence progress towards Aichi Target 14 for this habitat, since 2010 (Butchart *et al*., 2010), although work is underway to address this. In the western Himalayas, mountain ecosystems provide contributions to people ranging from water flow regulation to provision of materials, food and medicine, but extensive use of natural vegetation in the past has decreased the value of provisioning services (Khan *et al*., 2013), with increasing rarity of plants used for medicine by IPLCs (Díaz *et al*., 2006; Giam *et al*., 2010; Khan *et al*., 2012).

Loss of forests and native vegetation has affected smallholder subsistence systems by lowering yields, pollination, water provisioning, and access to animals and plants used as food, medicine and fuelwood, as well as aspects of human well-being including identity, autonomy, traditional lifestyles and knowledge (IPBES, 2018: 5.2.1). Deforestation and land degradation have had a negative impact on freshwater quality and quantity (IPBES, 2018: 5.2.3.). Approximately half of global population is expected to be living in water scarce areas by 2050, especially in Asia (IPBES, 2018: 7.2.4). Loss of native vegetation has also been linked to increase in flood-related disasters and soil erosion (IPBES, 2018: 5.3.2, 5.3.3).

Pollination services undertaken by feral colonies of honey bees and native insects are essential to crops and natural ecosystems (Gallai *et al*., 2009); animal pollination is directly responsible for between 5–8% of current global agricultural production by volume (IPBES, 2016). However, wild pollinators have declined in distribution and diversity (and in some cases, abundance) at local and regional scales in North West Europe and North America, the only regions with adequate data; local declines have been recorded elsewhere (IPBES, 2016). According to the IUCN Red List, 16.5% of vertebrate pollinators are threatened with global extinction, while the Red List Index for vertebrate pollinators is declining (**Table 3.3**; Regan *et al*., 2015), indicating that their extinction risk is increasing. In Europe, 9% of bee and butterfly species are threatened, and populations are declining for 37% of bees and 31% of butterflies (IPBES, 2016). Where national Red List assessments are available, they show that often more than 40% of bee species may be threatened (IPBES, 2016). These results suggest that the ecosystems upon which pollinators depend are not being sustained, and hence that we are moving away from meeting Target 14 for this component of nature's contribution to people.

Protected areas are a key mechanism for safeguarding ecosystems that provide essential services, and hence potentially play a key role in achieving Target 14 (IPBES, 2018: 7.2.2.2; Larsen *et al*., 2012). Protected areas deliver 20% of the global total of continental runoff, providing freshwater to nearly two thirds of the global population living downstream (Harrison *et al*., 2016). Positive conservation and socioeconomic outcomes are more likely to occur when protected areas are co-managed, empower local people, reduce economic inequalities, and maintain livelihood benefits (Oldekop *et al*., 2016). Co-management of protected areas by local communities and conservation agencies tends to be associated with delivery of greater local benefits than community– or state-management, according to a global meta-analysis of 171 studies involving 165 protected areas (Oldekop *et al*., 2016; see also chapter 6).

Elsewhere, restoration efforts are helping to recover nature's contributions to people, such as coastal protection from mangrove restoration (IPBES, 2018: 5.3.2), while multiple benefits are expected from forest restoration initiatives (IPBES, 2018: 6.5).

The global pattern of poor progress towards Target 14 is reflected in Asia-Pacific, but trends in West Asia, Latin America and the Caribbean are judged to be negative, while there is insufficient information to assess progress in Africa (UNEP-WCMC, 2016a, 2016b, 2016c, 2016d).

Aichi Target 15: Enhancing ecosystem resilience and the contribution of biodiversity to carbon stocks through conservation and restoration

Insufficient data are available to assess progress towards Aichi Target 15, but plausible scenarios suggest poor progress owing to increasing demands for commodities, water and energy from demographic growth and affluence gains (IPBES, 2018: 7.2). Assessing progress towards Target 15 is challenging owing to lack of agreement on how to measure ecosystem resilience, absence of baseline data on land degradation (IPBES, 2018: 7.2, 4.1.4) and lack of standardized protocols for measuring and reporting soil erosion (García-Ruiz *et al*., 2015). Additionally, evaluations of the success of reforestation programs tend to focus on short-term establishment success indicators and fail to assess long-term growth, maturation success and socioeconomic indicators (Adams *et al*., 2016; Le *et al*., 2012). Regional assessments indicate that slow progress is being made towards Target 15 in West Asia, while there is no significant progress in Africa. In Europe, there is an international agreement on the inclusion of greenhouse gases and removals from land use, land use change and forestry in the 2030 climate and energy framework. All regions suffer from a lack of data for assessing progress (UNEP-WCMC, 2016a, 2016b, 2016c, 2016d).

Historical loss of soil organic carbon due to land cover and land use change is estimated between 50 and 176 Gt C, mainly from topsoil in croplands, and future scenarios project a loss of 65 Gt C up to 2050 (IPBES, 2018: 7.2.1). In the tropics, conversion of primary forest into other land cover/use has been shown to cause soil organic carbon losses of 30% for conversion to perennial crops, 25% for other cropland and 12% for grassland (Don *et al*., 2011). Soil erosion is a global problem (IPBES, 2018: 4.2), and agricultural land use tends to be associated with the highest erosion rates (García-Ruiz *et al*., 2015). Land degradation is also the main stressor affecting freshwater ecosystems and water security (Vörösmarty *et al*., 2010). Climate change-induced droughts and expansion of drylands exacerbates the risks of land degradation (IPBES, 2018: 4.2).

Although there is no comprehensive global map of degraded lands or restoration efforts, a global analysis of forest restoration opportunities indicated that two billion hectares of degraded land are available for forest restoration (Potapov *et al*., 2011) and current efforts for large-scale forest restoration have proposed a goal of 350 million hectares to be restored by 2030 (Chazdon & Uriarte, 2016). Potential areas for restoration include carbon-rich ecosystems such as tropical peatland forests (FAO & Wetlands International, 2012).

Aichi Target 16: Operationalizing the Nagoya Protocol on Access and Benefit-Sharing

Progress has been made in the implementation of the Nagoya Protocol, but the objectives of this target have only partially been met. The protocol has been in force and operational since 12 October 2014 and has received 107 ratifications as of June 2018. With respect to the second part of Target 16, many Parties are in the process of establishing a legal framework on access and benefit-sharing in order to make the Protocol operational at the national level. As of February 2018, 50-member state Parties have made information on national ABS measures available online and 52 have made the coordinates of a competent national authority for genetic resources available online (at the CBD Access and Benefit-Sharing Clearing-House; https://absch.cbd.int). Some Parties still lack the necessary capacity and financial resources to make the Protocol operational, although several capacity-building initiatives are underway to respond to these needs. Of the Parties that had ratified the Protocol by February 2018, 75 (71% of 105 Parties) and 30 non-Parties (28%) have adopted legislative, administrative and policy frameworks for the implementation of the Nagoya Protocol (an increase from 51 Parties and 29 non-Parties in 2016). At the international level, the agreed principles of access and benefit-sharing have been considered beneficial to protecting genetic resources and traditional knowledge from misappropriation, although at the local level there are challenges (Robinson & Forsyth, 2016; Rosendal & Andersen, 2016).

Aichi Target 17: Developing and implementing national biodiversity strategies and action plans

Moderate or good progress has been made towards development, adoption and implementation of National Biodiversity Strategies and Action Plans (NBSAPs). By March 2018, 190 of 196 Parties (97%) have developed NBSAPs, and 141 of these (74%) have revised them at least once (CBD, 2018a). The vast majority (92%) of NBSAPs submitted since the tenth Conference of the Parties have taken account of the Strategic Plan for Biodiversity (CBD 2018a). An analysis of the level of ambition set in national targets within the revised/updated NBSAPs developed by 154 countries in March 2018 found that the majority of national targets in the NBSAPs were similar or commensurate with the relevant global Aichi Target (CBD 2018a). One recent analysis found that the NBSAPs of 94 countries analyzed contained a total of 1,485 priority actions addressing the elements of Aichi Target 11 and 12, and these were assessed as having positive contributions for progress towards 15 other Aichi Biodiversity Targets (UNEP-WCMC & IUCN, 2016). The number of countries implementing NBSAPs is increasing, but several countries have not yet made progress in implementation (Marques *et al*., 2014). Further research is needed to develop indicators assessing the link between policies implemented and their outcomes (Bark and Crabot, 2016).

Aichi Target 18: Respecting and integrating traditional knowledge and customary sustainable use

Poor or moderate progress has been made towards integrating traditional knowledge and customary use into implementation of the Convention, despite IPLCs managing or having tenure rights over at least 38 million km^2 in 87 countries/territories on all inhabited continents (Garnett *et al*., 2018). Local studies indicate general declines in traditional knowledge (e.g., Hidayati *et al*., 2017); analysis of management and conservation by IPLCs is more easily conducted at the national level, and global assessments are lacking. There have also been recommendations for how traditional knowledge and the practices of IPLCs could be integrated better into relevant national legislation (e.g., Barpujari & Sarma, 2017) and international obligations, such as global patent systems (Amechi, 2015). While NBSAPs may include actions that respect and integrate traditional and local knowledge into implementation of the Convention, only 20% of 98 NBSAPs examined in 2016 mentioned customary sustainable use (CBD 2016a), and 34% of NBSAPS had no targets relating to Aichi Target 18 (CBD 2016b). Furthermore, participatory mechanisms are not fully operative yet, (for example, only 18% of Parties reported involvement of IPLCs in their NBSAPS in 2016; CBD 2016a), and there is often limited capacity to engage IPLCs meaningfully in policy decisions (Escott *et al*., 2015). Exceptions include some Arctic regions, where indigenous communities have a significant voice in policy decisions at local, national and international scales (Merculieff *et al*., 2017). Elsewhere, there is often still some resistance to the idea that conventional science can be complemented by local knowledge, despite examples showing that such an approach can help address environmental problems (Tengö *et al*., 2017). In countries where there is a strong legislative and policy framework surrounding Indigenous Peoples and community conserved territories and areas (ICCAs), they cover and conserve large areas. For example, in Namibia, where community-governed areas are formally recognised, ICCAs cover over 164,000 km^2 (UNEP-WCMC & IUCN, 2016). However, in some countries the lack of financial or human resources is hampering participatory approaches, while in others, support for community-based monitoring is limited its potential contribution is insufficiently recognised (Ferrari *et al*., 2015).

Aichi Target 19 Improving, sharing and applying knowledge of biodiversity

While knowledge, science and technologies relating to biodiversity have improved and been shared and applied, there has been poor or moderate progress towards Aichi Target 19. There has been substantial growth in knowledge on biodiversity and its dissemination (as illustrated by the numbers of scientific publications on biodiversity, relevant research funding, taxa assessed for the IUCN Red List, and species with data included in the Global Biodiversity Information Facility; **Table 3.3**), although this has often not translated into conservation actions (Geijzendorffer *et al*., 2017). Some aspects of biodiversity receive significantly more attention than previously but remain underrepresented; the total proportion of scientific articles relating to biodiversity that focus on invertebrates, genetic diversity, or aquatic systems is 50%–60% higher in 2011–2015 than it was before 2010 (Di Marco *et al*., 2017). However, greater attention is still given to areas or taxa less rich in biodiversity and threatened biodiversity, e.g., 40% of studies are carried out in USA, Australia or the UK, with only 10% in Africa and 6% in South-East Asia (Di Marco *et al*., 2017). A recent analysis quantified the funding required to maintain and expand key biodiversity and conservation knowledge products (Juffe-Bignoli *et al*., 2016a). Progress has been made in transfer of scientific knowledge and technologies from countries rich in resources to countries rich in biodiversity (Vanhove at al. 2017). However, the latter often have limited capacities for biodiversity monitoring, data gathering, and integration between science and policy, despite efforts of various initiatives (Schmeller *et al*., 2017) and notwithstanding the potential for IPLCs to contribute to monitoring (Zhao *et al*., 2016a). We lack sufficient information on the consequences of biodiversity loss for people, and appropriate indicators of the application of knowledge, science and technologies **(Table 3.3)**. However, it is likely that while the amount of biodiversity information is increasing, there has been less progress in the application of such information to inform decision-making (CBD 2016f), particularly by comparison with responses to tackle climate change (Legagneux *et al*., 2018; Veríssimo *et al*., 2014).

Aichi Target 20: Increasing financial resources for implementing the Strategic Plan for Biodiversity
While financial resources for implementing the Plan have increased, these are still insufficient for its effective implementation. The first report of the High-Level Panel on Global Assessment of Resources for implementing the Strategic Plan for Biodiversity 2011–2020 estimated that US$150–440 billion per year would be required to meet the Aichi Biodiversity Targets by 2020, depending on inter-linkages, policy coherence, institutional development, and synergies between targets and other goals (CBD 2016c). As inputs to this synthesis, McCarthy *et al*., (2012) estimated that US$3.41–4.76 billion would be needed per year to reduce the extinction risk of all known globally threatened species and hence contribute to one part of Aichi Target 12, but that only 12% of needs are currently funded for threatened birds, one of the better-funded groups. Similarly, these authors estimated that US$76.1 billion per year is needed to conserve areas of particular importance for biodiversity, but that funding needs to increase by at least an order of magnitude (McCarthy *et al*., 2012).

There has been significant growth in Official Development Assistance in support of the CBD and funding provided by the Global Environment Facility, but no significant increase in global funding committed to environmental policy, laws and regulations **(Table 3.3)**. While biodiversity aid flows have been boosted by concern about climate change (Donner *et al*., 2016) and have reached up to $8.7 billion annually (including projects for which biodiversity conservation is only a secondary objective; OECD, 2017), this falls far below the levels needed to support progress toward international conservation goals (Tittensor *et al*., 2014), including for protected areas and threatened species (McCarthy *et al*., 2012; UNEP-WCMC & IUCN, 2016). The countries that are least adequately funded are typically developing nations with high biodiversity and many threatened species. Furthermore, they are often neighbors, which affects taxa across their entire ranges, increasing the risk of extinction. This latter effect is of particular concern in the Malaysia–Indonesia–Australia region and in arid and semi-arid lands across Central Asia, Northern Africa, and the Middle East (Waldron *et al*., 2013).

3.2.2 Synthesis of progress globally

Overall, we have made good progress towards elements of four of the 20 Aichi Biodiversity Targets (9, 11, 16, 17) under the Strategic Plan on Biodiversity, and moderate progress towards some elements of another seven targets (1,2,7,13, 18, 19, 20), but for six targets (3, 4, 5, 8, 10, 12) we have made poor progress towards all elements, while we have insufficient information to assess progress for some or all elements of the remaining three targets (6, 14, 15; **Figure 3.6**). Of the 54 elements, we have made good progress towards five (9%), moderate progress towards 19 (35%) and poor progress or movement away from the target for 21 (39%). Progress is unknown for nine elements (17%) **(Figure 3.6)**. The strongest progress has been towards identifying/prioritizing invasive alien species (Target 9), conserving 10% of coastal/marine areas and 17% of terrestrial and inland water areas (Target 11), bringing the Nagoya Protocol into force (Target 16), and developing National Biodiversity Strategies and Action Plans (Target 17). While protected areas now cover 14.9% of the terrestrial realm, 17.2% of marine areas within national jurisdiction and 7.44% of the ocean (as of September 2018), and prospects are very high for exceeding the area thresholds (17% terrestrial and inland waters, 10% marine and coastal) providing country commitments are fulfilled **(Figure 3.3a)**, the global protected area network only partly covers the most important sites for biodiversity, and is not yet fully ecologically representative, effectively and equitably managed or adequately resourced. Furthermore, while some species have been brought back from the brink of extinction, achieving local successes towards Target 12 (preventing extinctions), for all taxonomic groups with known trends, overall, species are moving towards extinction at an increasing rate. Least progress has been made towards Target 10 (addressing drivers impacting coral reefs and other ecosystems vulnerable to climate change).

We have made more progress towards implementing policy responses and actions to conserve nature and use it more sustainably (22 of 34 indicators show significant increases) than has been achieved in addressing the drivers of biodiversity loss (9 of 13 indicators show significantly worsening trends). As a result, the state of nature overall continues to decline (12 of 16 indicators show significantly worsening trends) **(Figure 3.5)**. Indicators for the Targets under Goal B addressing anthropogenic drivers of biodiversity loss, including habitat loss (target 5), fisheries (6), agriculture, aquaculture and forestry (7), pollution (8) invasives (9) show that many of these drivers are increasing despite efforts to meet the Targets. Trends in the magnitude of Nature's Contributions to People (NCP) are less well known, but four of five indicators show significantly worsening trends. Trends in the magnitude of nature's contributions to people are less well known, but four of five indicators show significantly worsening trends **(Figure 3.5)**. Declines in the state of biodiversity suggest that any current positive trends for other benefits from nature are likely to be unsustainable. These patterns mirror those found by Tittensor *et al*., (2014), but the larger number of indicators, and the longer time series, strengthen these conclusions **(Figure 3.5)**. Only eight indicators showed different trends between this assessment and Tittensor *et al*. (2014). Three provided a more positive assessment in terms of progress towards targets (Ecological Footprint, Mean polar sea ice extent, Official development assistance provided in support of CBD objectives), while five provided

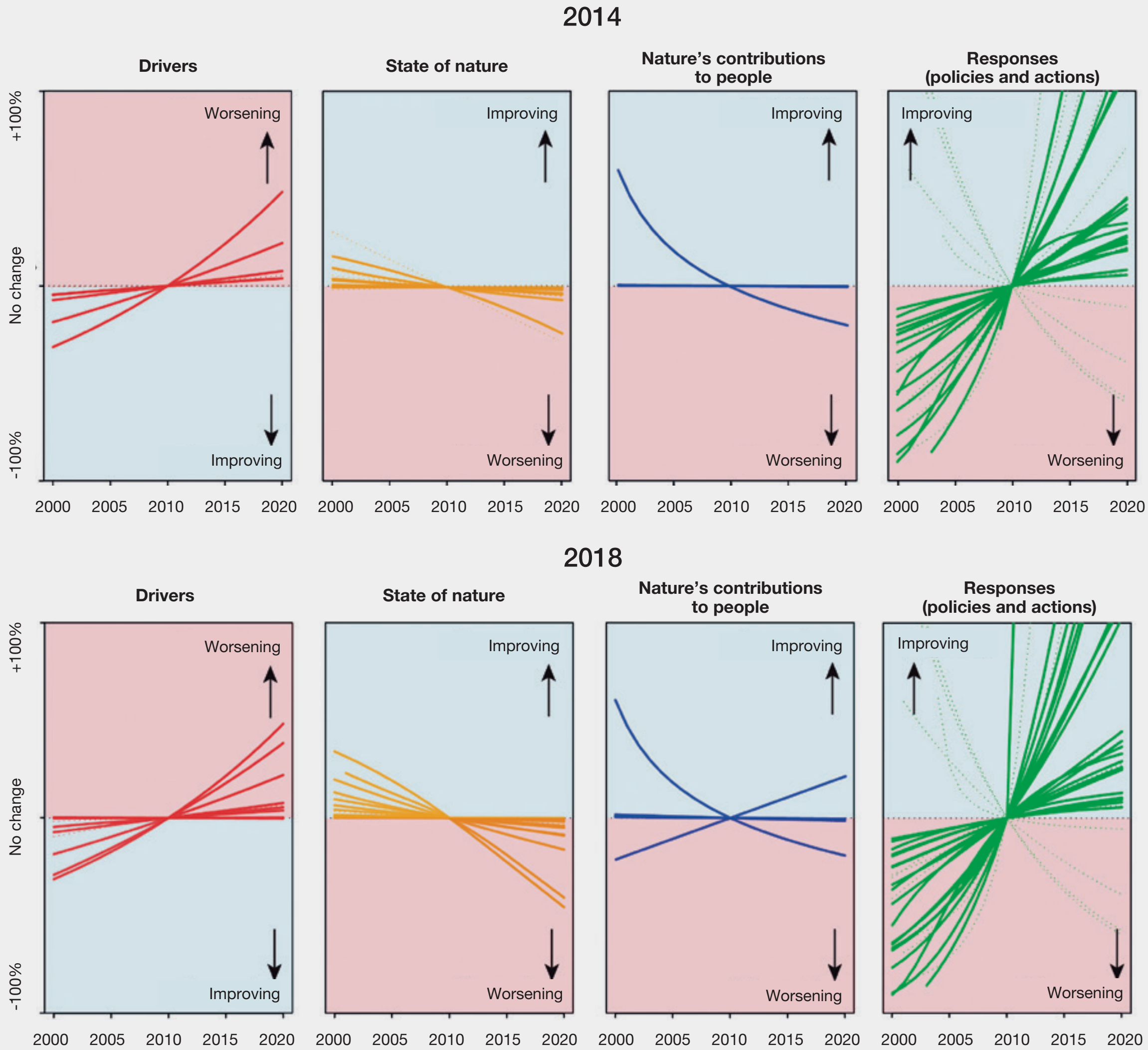


Figure 3 5 **Trends in indicators of drivers, the state of nature, nature's contributions to people, and responses (policies and actions of institutions and governance) across all Aichi Biodiversity Targets, as assessed in Tittensor *et al.* (2014), and for this assessment in 2018.**

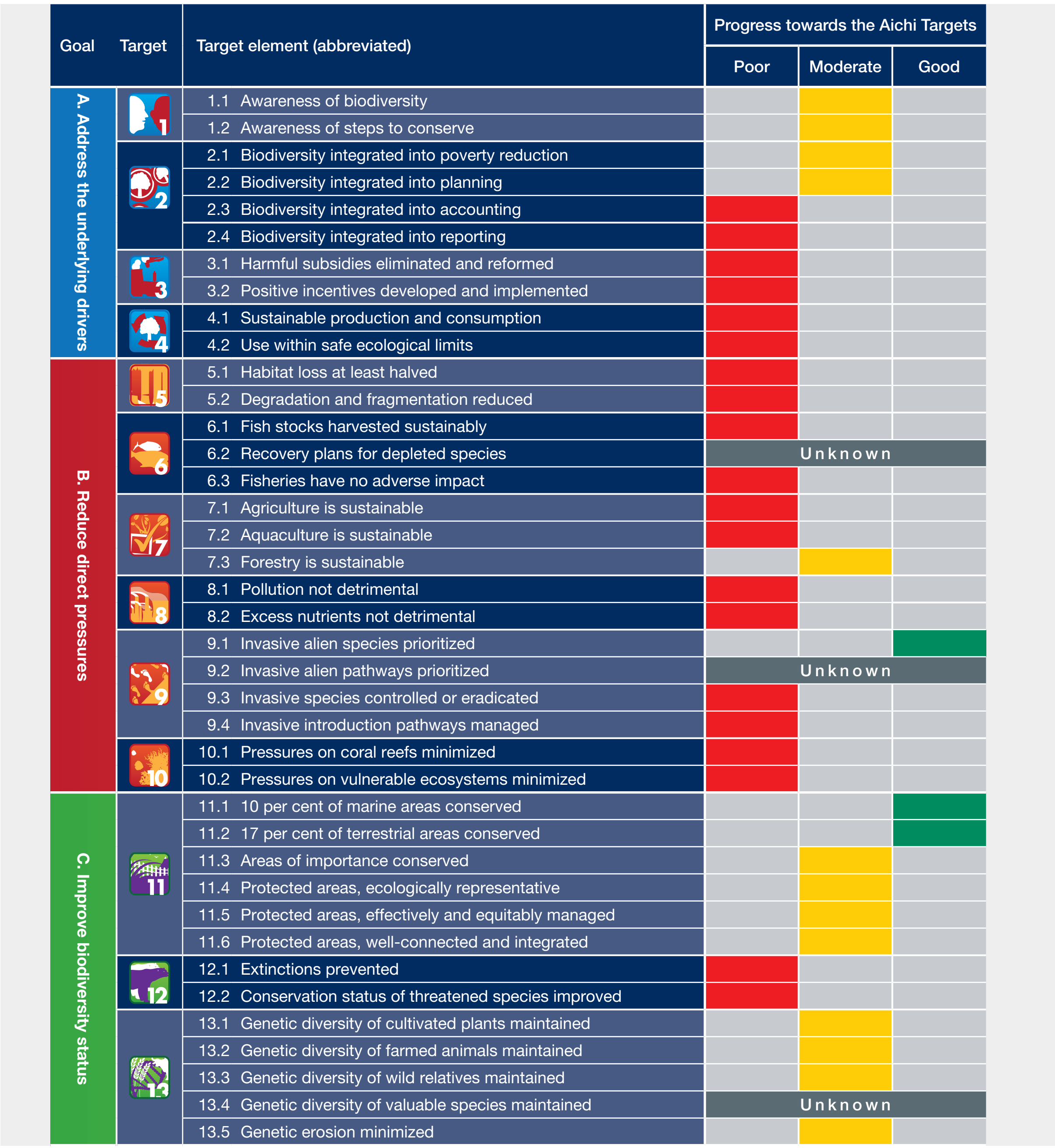
Lines represent significant (continuous) or nonsignificant (dotted) trends relative to 2010 modelled value (horizontal dotted black line). Indicators with very flat linear trends may be superimposed (e.g., two indicators of nature's contributions to people). An increase in indicators of the state of nature, nature's contributions to people, and responses, or a decrease in drivers, represents progress toward the targets. Some indicator trends (e.g., extinction rates) have been inverted to conform to this paradigm. Trends have been truncated before 2000 for visualization purposes.

a more negative assessment (World Trade Organization 'greenbox' agricultural subsidies, Percentage natural habitat extent, Wild Bird Index for habitat specialists, Pesticide use, Glacial mass balance). In almost all cases, the trends were identical but changed from significant to non-significant, or *vice versa*.

In most cases, there is insufficient information to quantify what the trends would have been in the absence of conservation action and policy responses to the Aichi Biodiversity Targets. Some evidence is available for some elements of some targets. For example, for Target 12, extinction risk trends shown by the Red List Index for birds and mammals would have been worse in the absence of conservation (Hoffmann *et al*., 2010), with at least six species of ungulate species likely to now be extinct or surviving only in captivity without conservation during 1996–2008 (Hoffmann *et al*., 2015). For Target 9, at least 107 highly threatened birds, mammals, and reptiles are estimated to have benefitted from invasive mammal eradications on islands (Jones *et al*., 2016). However, there are few other counterfactual studies assessing how trends in the state of nature or pressures upon it would have been different in the absence of conservation efforts.

We lack quantitative indicators suitable for extrapolation to judge progress towards some elements of 13 Aichi Biodiversity Targets, and over one third (19/54, 35%) of all elements across all Targets, meaning that assessment has to rely on more qualitative assessment of the literature. For Target 15 (ecosystem resilience and contribution of biodiversity to carbon stocks) the lack of both quantitative indicators and qualitative information means that no assessment of progress was possible **(Figure 3.6)**. Target 18 (integration of traditional knowledge and effective participation of indigenous and local communities) also lacked any indicators that were suitable for statistical extrapolation, while lack of both indicators and qualitative information precluded assessment of one element of each of Targets 6 (on sustainable fisheries) and 14 (on ecosystem services) **(Figure 3.6)**.

Our results mirror the pattern found by Tittensor *et al.* (2014) and the Global Biodiversity Outlook 4 (Secretariat of the CBD, 2014), but the larger sample of indicators (68 vs. 55) and updated time series of our analysis show an even clearer pattern of increasing drivers and responses, but declining trends in the state of nature and NCP **(Figure 3.5)**.



Goal	Target	Target element (abbreviated)	Progress towards the Aichi Targets		
			Poor	Moderate	Good
D. Enhance benefits to all	14	14.1 Ecosystems providing services restored and safeguarded			
		14.2 Taking account of women, IPLCs, and other groups	Unknown		
	15	15.1 Ecosystem resilience enhanced	Unknown		
		15.2 15 per cent of degraded ecosystems restored	Unknown		
	16	16.1 Nagoya Protocol in force			
		16.2 Nagoya Protocol operational			
E. Enhance implementation	17	17.1 NBSAPs developed and updated			
		17.2 NBSAPs adopted as policy instruments			
		17.3 NBSAPs implemented			
	18	18.1 ILK and customary use respected			
		18.2 ILK and customary use integrated	Unknown		
		18.3 IPLCs participate effectively	Unknown		
	19	19.1 Biodiversity science improved and shared			
		19.2 Biodiversity science applied	Unknown		
	20	20.1 Financial resources for Strategic Plan[a] increased			

Figure 3 6 **Summary of progress towards the Aichi Biodiversity Targets.**

Scores are based on quantitative analysis of indicators, a systematic review of the literature, fifth National Reports to the CBD, and available information on countries' stated intentions to implement additional actions by 2020. Progress towards target elements is scored as "Good" (substantial positive trends at a global scale relating to most aspects of the element), "Moderate" (the overall global trend is positive but insubstantial or insufficient, or there may be substantial positive trends for some aspects of the element but little or no progress for others, or the trends are positive in some geographic regions but not in others), "Poor" (little or no progress towards the element or movement away from it; while there may be local, national or case-specific successes and positive trends for some aspects, the overall global trend shows little or negative progress) or "Unknown" (insufficient information to score progress). IPLCs = Indigenous Peoples and Local Communities; NBSAPs = National Biodiversity Strategies and Action Plans; ILK = Indigenous and Local Knowledge. Numbers for target elements match those in **Table 3.3**.

3.2.3 Assessment of progress regionally and nationally

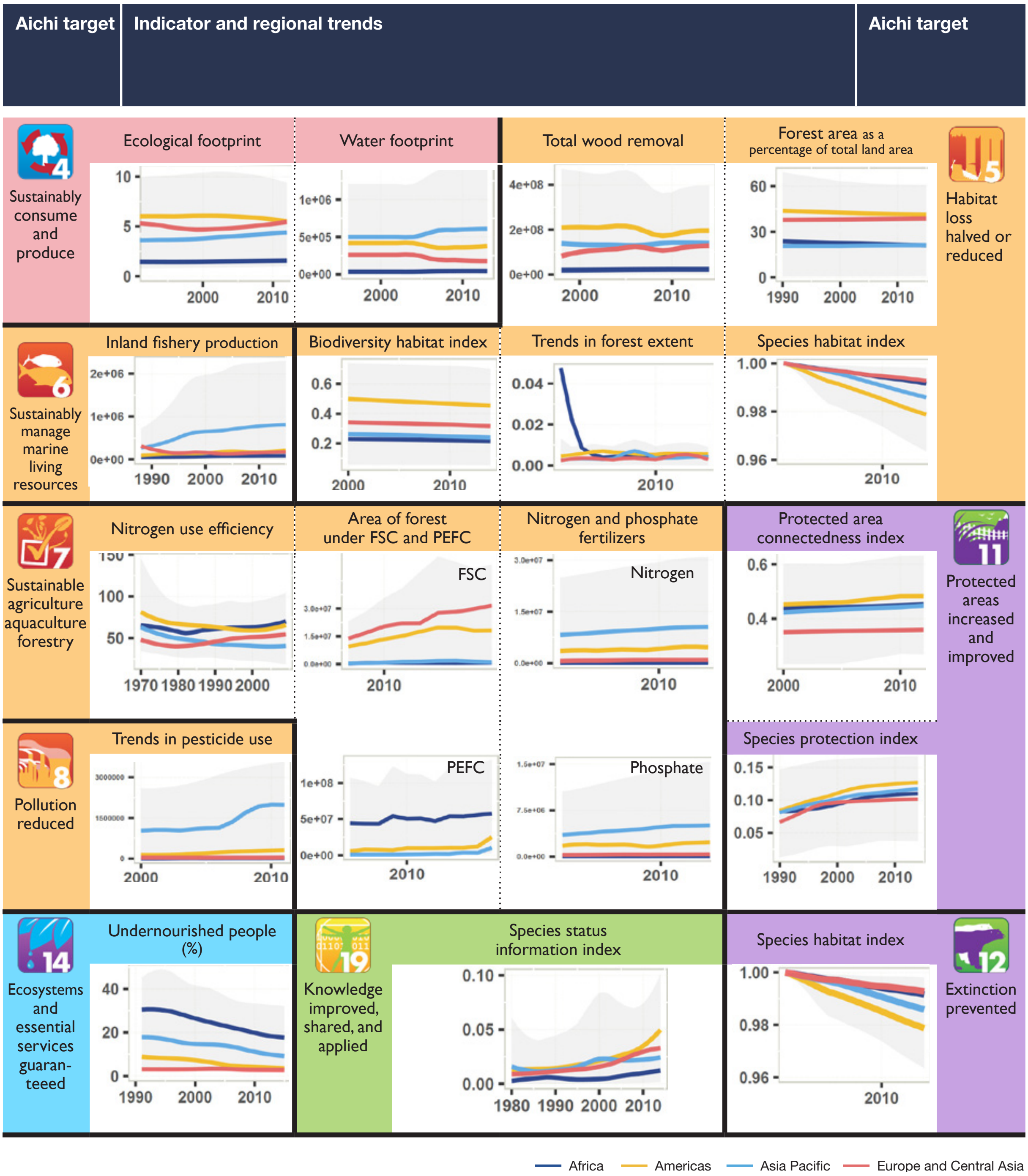
For a set of indicators addressing nine targets, observed trends for four different IPBES regions (Africa, Americas, Asia-Pacific and Europe and Central Asia) regions are shown in **Table 3.4**. For many indicators, regions differ in absolute level of progress, highlighting known historical and recent differences in the status of biodiversity and ecosystem services. Regional positions vary by target, and no region is consistently at the bottom or top. Regional differences in trends were more limited, which is not surprising given the relatively short time-frame analyzed. Notably differences existed for the Species Habitat Index where the Americas and Asia-Pacific saw a much greater deterioration and more limited progress to achieving Targets 5 and 11 than the other regions. Trends in Pesticide Use increased particularly strongly in Asia-Pacific, suggesting a potentially more limited progress to Target 8 there. As final example, the Americas stood out as making particularly strong progress toward closing biodiversity knowledge gaps (Target 19).

A separate analysis applied the methods used for **Table 3.3** and extrapolated trends to 2020 for each of the IPBES regions for six indicators for which data were available (Area of tree cover loss, Marine Stewardship Council certified fisheries, Marine trophic index, Pesticide use, Percentage of Key Biodiversity Areas covered by protected areas, and Species Status Information Index). Here, trends were similar across all regions, with the exception of Europe and Central Asia, in which trends were more positive. For example, it was the only region which experienced a significant increase in the Marine trophic index (other regions had significant or non-significant decreases), the only region with a decrease (albeit non-significant) in the area of tree cover loss, and the only region alongside Africa in which the increase in pesticide use was non-significant. However, overall there are too few quantitative results in **Tables S3.2** and **3.4** to draw robust conclusions about regional variation in progress towards the Aichi Biodiversity Targets. Qualitative information from a review of the literature also did not reveal strong and consistent regional differences in terms of progress towards the Aichi Biodiversity Targets.

The Aichi Biodiversity Targets are largely implemented nationally. Under the CBD, Parties develop NBSAPs to plan such implementation, and National Reports to document the outcomes. CBD (2016d) assessed the level of alignment of national targets set in revised/updated NBSAPs (available

Table 3 4 **Regional trends for selected indicators relevant to selected Aichi Biodiversity Targets.**

Graphs show the smoothed trend in average indicator values for each of the four IPBES regions (Africa: navy, Americas: gold, Europe and Central Asia: coral, Asia-Pacific: sky blue). Grey areas delineate the central 90% of variation among countries. Regional values account for the different sizes of countries, and lines characterize the trends of a region's average-sized country. The indicators shown are those considered by the IPBES indicators task group to be relevant to particular Aichi Biodiversity Targets, appropriate for weighting national values by country size, and for which trends are available for IPBES regions.



for 52% of Parties) to the global Aichi Biodiversity Targets, and progress towards achieving these described in the 5th National Reports (available for 90% of Parties). RSPB *et al*. (2016) synthesized the results by comparing average scores across targets **(Figure 3.7)** and found that only 10% of countries have set national targets that equal or exceed the global level of ambition, while c.40% of countries were less ambitious and 50% of countries have targets that are significantly lower in ambition. In particular, Target 2 (integrating biodiversity values into development,

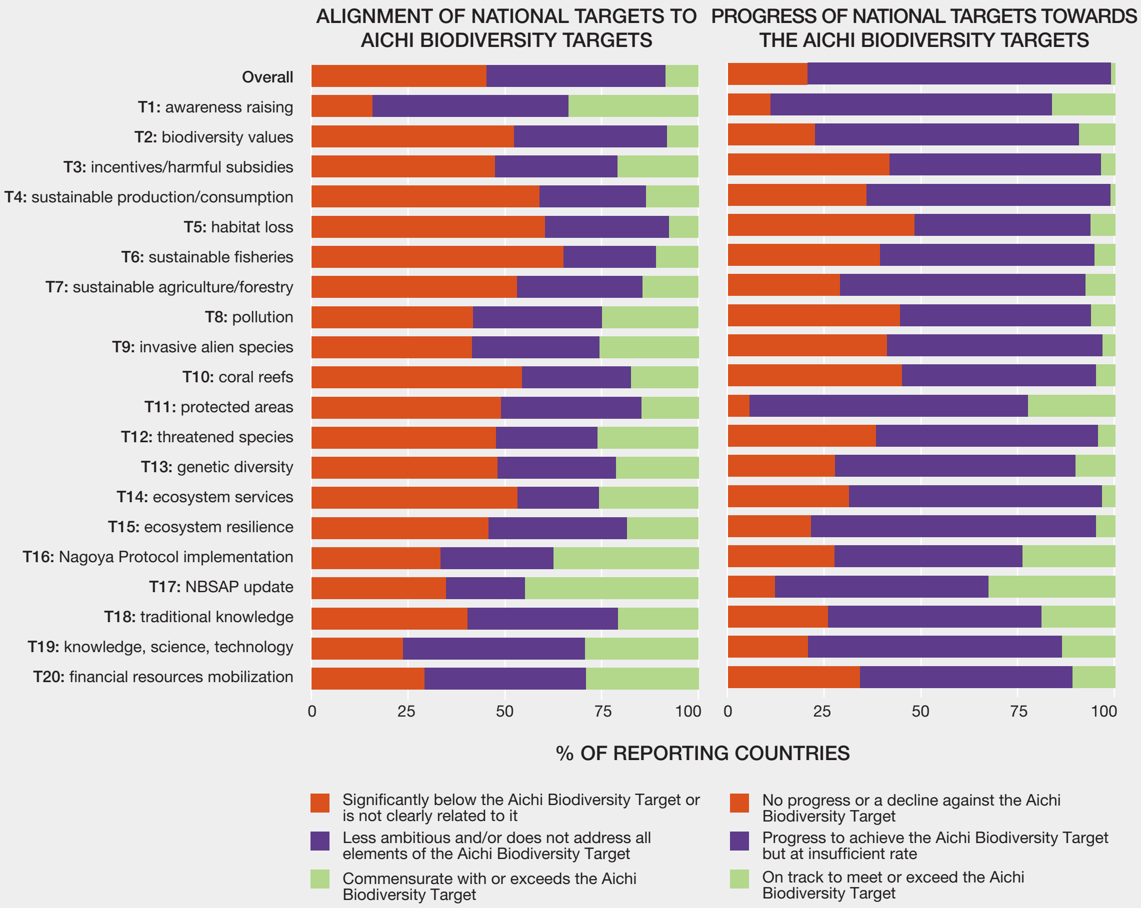


Figure 3 7 **Alignment of national targets (set in National Biodiversity Strategies and Action Plans) to the global Aichi Biodiversity Targets, and progress towards achieving them (described in 5th National Reports to the Convention on Biological Diversity).**

Source: RSPB *et al.* (2016) based on data in CBD (2016d).

poverty reduction and national accounting) and Targets 5 to 7 in Strategic Goal B (reducing direct pressures on biodiversity and promoting sustainable use) are those for which countries least ambitious. Targets 1 (awareness raising), 16 (implementation of the Nagoya Protocol), and 17 (development, adoption and implementation of NBSAPs) are those for which countries have been most ambitious compared with the global Targets (**Figure 3.7**; RSPB *et al.*, 2016). An updated assessment by CBD (2018f) found similar results and concluded that the majority of national targets and/or commitments contained in NBSAPs were lower than the Aichi Biodiversity Targets or did not address all of the elements of the Aichi Target.

In relation to progress, only about 5% of countries' National Reports indicate that they are on track to meet the global targets, while 75% have made progress but insufficient to meet the global level of ambition by 2020. Of greatest concern, 20% of National Reports indicate that countries have made no progress or have moved away from the global targets. Countries report that their progress has been greatest towards Targets 1, 16 and 17, as noted above, but also Targets 11 (relating to protected areas) and 18 (on traditional knowledge and customary use of biological resources). Least progress is reported towards Target 4 (on sustainable production and consumption) and 9 (addressing invasive alien species). Underpinning these patterns, 34% of countries indicate no progress towards Target 20 (on resource mobilization), 55% have made insufficient progress, and only 11% are on track to meet or exceed the global level of ambition (**Figure 3.7**; CBD 2016d; RSPB *et al.*, 2016). An updated assessment by CBD (2018f) found similar results and concluded that the majority of Parties have made insufficient progress to allow the Aichi Biodiversity Targets to be met by the deadline unless additional actions are taken, with proportion of Parties not on track to attain a given target ranging from 63% to 86%.

These results on national ambition and progress, which indicate that 95% of countries are behind schedule (CBD 2016d; RSPB *et al*., 2016) help to explain the global and regional patterns reported above.

3.2.4 The Aichi Biodiversity Targets and Indigenous Peoples and Local Communities

IPLCs are conducting many collective and on-the-ground actions that contribute to achieving the Aichi Biodiversity Targets and the SDG. The international Indigenous Forum on Biodiversity (IIFB), a platform for IPLC participation in the CBD, has published the Local Biodiversity Outlooks as a contribution to mid-term monitoring of the Strategic Plan for Biodiversity (Forest People's Programme *et al*., 2016). The report highlights the contributions of IPLCs and the challenges and opportunities for enhanced national implementation of these international commitments. It also highlights the importance of recognizing IPLCs as legitimate stakeholders and their knowledge system as valuable knowledge in achieving these goals in collaboration with other stakeholders (Sikor & Newell, 2014; Sikor *et al*., 2014; also see chapter 1).

Building upon the Local Biodiversity Outlook and based on systematic literature review, we review 1) the contribution of IPLCs' efforts to achieve the Aichi Biodiversity Targets, and 2) the significance of achieving each target to IPLCs. Detailed accounts for each Aichi Target are provided in the Supplementary Materials, section S3.3. We focus on the positive contributions that IPLCs make to achieve targets and goals but recognize that there are exceptions and note some in the text.

Aichi Target 1: Increasing awareness of biodiversity
IPLCs have played a crucial role in raising awareness of biodiversity diverse values from local to global scales (Athayde, 2017; Bali & Kofinas, 2014; Rathwell & Armitage, 2016; Singh *et al*., 2017). They have substantially contributed to initiate, maintain and strengthen initiatives (e.g., cultural events, written and audiovisual material) for communicating, educating and raising awareness about biodiversity (Horton, 2017; FPP *et al*., 2016; Janif *et al*., 2016; Veríssimo *et al*., 2018). Many of these actions have been orchestrated through IPLC organizations and networks, such as the International Indigenous Forum on Biodiversity (IIFB) and the Traditional Knowledge Information Portal (TKIP) of the CBD. IPLC-led awareness-raising campaigns often reveal conceptualizations of nature that differ substantially from Western epistemologies, promoting recognition towards the intrinsic values of nature, and acknowledging its spiritual dimension (e.g., Aniah & Yelfaanibe, 2016; Chen & Gilmore, 2015; Parotta & Trosper, 2012; also see chapter 1). IPLC narratives on the environment often build on philosophical concepts such as the mutual reciprocity between humans and nature (Kimmerer, 2011; Kohn, 2013; Nadasdy, 2007), webs of relationality and kin (Aiyadurai, 2016; Descola, 1996), lack of a nature-culture divide (Caillon *et al*., 2017; De La Cadena, 2010; Zent, 2013), promotion of relational approaches to nature (Comberti *et al*., 2015; Kopenawa & Albert, 2013), and powerful stewardship ethics (Dove, 2011; Gammage, 2011). Lack of awareness of biodiversity and its multiple values is one of the main drivers of the current conservation crisis (Balmford, 2002; Lindemann-Maties & Bose, 2008; Snaddon *et al*., 2008). There is well established evidence that many IPLCs currently face cultural and economic pressures that threaten their connections with the environment (Ford *et al*., 2010; Godoy *et al*., 2005; Luz *et al*., 2017; Reyes-García *et al*., 2014). Monetary valuation of biodiversity and NCP is increasingly emphasized in policy reports (Brander & van Beukering, 2013), whereas the intangible benefits of biodiversity continue to be largely overlooked (Boeraeve *et al*., 2015; Hausmann *et al*., 2016). Similarly, advertisement campaigns by pro-environmental NGOs have often used 'threatening' messages to raise biodiversity awareness (Weberling *et al*., 2011; Weinstein *et al*., 2015), failing to capitalize upon IPLCs cultural values and intrinsic motivation to conserve nature (Hazzah *et al*., 2014; García-Amado *et al*., 2013; van der Ploeg *et al*., 2011). Innovative art-based participatory methods are increasingly engaging IPLCs in biodiversity conservation (Bali & Kofinas, 2014; Heras & Tàbara, 2014, 2016). Education programs integrating ILK are also playing a significant role in promoting awareness of the multiple values of biodiversity amongst IPLCs (Hamlin, 2013; Mokuku, 2017; McCarter & Gavin 2011, 2014; Thomas *et al*., 2014). IPLCs are also engaging in ecotourism initiatives, the certification of local agricultural products, and initiatives to utilize forgotten traditional wild food plants (Łuczaj *et al*., 2012; Reyes-García *et al*., 2015), which help to raise awareness about biodiversity (Bluwstein, 2017; Espeso-Molinero *et al*., 2016; Mendoza-Ramos & Prideaux, 2017; Stronza & Gordillo, 2008).

Aichi Target 2: Integrating biodiversity values into development, poverty reduction, planning accounting and reporting
Despite numerous efforts from IPLCs in communicating ideas of environmental governance based upon reciprocity (Belfer *et al*., 2017; Raatikainen and Barron, 2017), little or no progress has been achieved in the inclusion of IPLCs biodiversity values into development or poverty reduction. For instance, although Standing Rock Sioux Tribe members have tried to communicate the importance of their territory in maintaining water flows and local biodiversity levels, priority has been given to the construction of an oil pipeline that crosses sacred lands (Raffensperger, 2014). In some cases, however, IPLCs biodiversity values have been mainstreamed into national development and conservation policies,

recognizing the rights of non-human actors and ecosystems (Haraway, 2016). Examples include the Ecuadorian and Bolivian Constitutions where Pachamama ('Mother Earth') has rights, and New Zealand's recognition of Te Urewa legal personhood. However, implementing such approaches in development and poverty reduction policies has proven difficult, as ecosystems do not have a voice in courtrooms when their existence is at risk (McNeill, 2017; Temper and Martinez-Alier, 2016), and IPLC's value systems are often simplified (Bidder *et al*., 2016; Griewald *et al*., 2017; Jacobs *et al*., 2016). For example, *Sumak Kawsay* is a Quechua term that means "living well". In recent years the term "*buen vivir"* has also been used by other actors with purposes that might differ from those originally intended by IPLCs (Perreault, 2017). A shift from top-down environmental policy to bottom-up inclusive socio-ecological policy requires: (i) the recognition of the importance of socially and historically contextualized scientific knowledge (Kolinjivadi *et al*., 2016; Pascual *et al*., 2017); (ii) the expansion of the value system related to biodiversity to include relational values along with utilitarian and non-utilitarian values in nature (Chan *et al*., 2006; Kosoy and Corbera, 2010); and (iii) the inclusion of non-human stakeholders as legitimate actors in social-ecological system (Culinam, 2011; Saito, 2017).

Aichi Target 3: Eliminating harmful incentives and developing and applying positive incentives for biodiversity conservation and sustainable use

Positive incentives to halt biodiversity loss, such as Reducing Emissions from Deforestation and Forest Degradation (REDD+) and Payments for Ecosystem Services (PES), can bring both opportunities and challenges for IPLCs (Aguilar-Stoen, 2017; Godden & Tehan, 2016; Larson *et al*., 2013; Loaiza *et al*., 2016). Positive incentives are more effective in halting biodiversity loss if they are grounded in the relative values people attach to environmental impacts (Babai *et al*., 2015; Baskaran *et al*., 2009) while integrating traditional management systems with scientific and institutional inputs (Chandrasekhar *et al*., 2007; Molnár *et al*., 2016; Riseth, 2007). Challenges to IPLCs from positive incentives include 'elite capture' (Calvet-Mir *et al*., 2015), increased income inequality, and motivational crowding out after economic incentives stop (Corbera, 2012). Including IPLCs in the design of positive incentives can help tackle these risks and increase the potential for securing multiple biodiversity values and contributing to community quality of life (Spiric *et al*., 2016). Perverse incentives (e.g., those awarded to extractive industries) or incentives that are not adapted to ecological and social contexts (e.g., decoupling payments from production) are not effective in reconciling conservation and development goals (Santos *et al*., 2015) and directly affect biodiversity and IPLCs (Abdollahzadeh *et al*., 2016; Acharya *et al*., 2015; Diaz *et al*., 2015; Ribeiro *et al*., 2014; Roder *et al*., 2008). Eliminating such perverse incentives is a priority from both a biodiversity and a human rights perspective (Vadi, 2011).

Aichi Target 4: Implementing plans for sustainable production and consumption

IPLCs offer many examples of how economies built on ILK can contribute to sustainable production and consumption (e.g., Cedamon *et al*., 2017; Cuthbert, 2010; Okia *et al*., 2017; Ouédraogo *et al*., 2017; Perfecto & Vandermeer, 2010; Tolley *et al*., 2015; Valente & Negrelle, 2013). IPLCs contribution to natural resources sustainable production includes water (Schnegg & Linke, 2016; Vos & Boelens, 2014), energy (Parker *et al*., 2016; Pilyasov, 2016), fisheries (Bravo-Olivas *et al*., 2014; Wiber *et al*., 2010) and ecosystems/environments (Kimmel *et al*., 2010; Rebelo *et al*., 2011) such as mountains (Gratzer & Keeton, 2017), pasture lands (Fernández-Giménez, 2000; Kis *et al*., 2017; Meuret & Provenza, 2014; Tessema *et al*., 2014), agricultural land (Barrios *et al*., 1994; Kahane *et al*., 2013; Schulz *et al*., 1994) and forests (Hajjar, 2015; Meyer & Miller, 2015). Some studies have demonstrated that such initiatives are within safe ecological limits (e.g., Bravo-Olivas, 2014 for coastal fisheries; Brown *et al*., 2011 and Faude *et al*., 2010 for forests; and Cuthbert, 2010 for hunting), but more research on the topic is needed. The examples provided by IPLCs are particularly relevant as the expansion of commodity production driven by unsustainable consumption and production patterns exerts direct pressures on IPLCs and their lands (Dell'Angelo *et al*., 2017; De Schutter, 2011; Moore, 2000; Orta & Finer, 2010), sometimes also changing their production and consumption patterns (e.g., Luz *et al*., 2017). Unsustainable production of natural resources has resulted in many conflicts involving IPLCs, including over biofuels (Amigun *et al*., 2011; Nesadurai, 2013; Pilcher, 2013; Sawyer, 2008), energy (Andre, 2012; Baumert *et al*., 2016), mining (Ncube-Phiri *et al*., 2015), industrial development (Pilyasov, 2016), agriculture (Kahane *et al*., 2013), water use (Vos & Boelens, 2014), forest management (Carter & Smith, 2017; Grivins, 2016; Ribot *et al*., 2010), marine resources (Rebelo *et al*., 2011; Thomson, 2009), sport hunting (Yasuda, 2011), and pastoralism (Yonas *et al*., 2013). The contributions of IPLCs to sustainable production and consumption are recognized mostly when the contribution of ILK systems is acknowledged (e.g., Bardsley & Wiseman, 2016; Kahane *et al*., 2013; Kumagai & Hanazaki, 2013; Lane, 2006; Queiroz, 2011).

Aichi Target 5: Reducing the loss, degradation and fragmentation of natural habitats

Many of the world's biodiversity-rich natural habitats overlap with IPLCs' lands and territories (Garnett *et al*., 2018; Maffi, 2005; Nietschmann, 1987; Sunderlin *et al*., 2005; Toledo, 2001). A growing body of literature provides evidence that IPLCs can contribute to forest conservation (Blackman *et al*., 2017; Ceddia *et al*., 2015; Nolte *et al*., 2013; Porter-Bolland *et al*., 2012), although there is less evidence for other terrestrial habitats (but see Busilacchi *et al*., 2013; Williams *et al*., 2008). IPLCs may contribute to forest conservation through customary practices such as sacred forests (Assefa & Hans-Rudolf, 2017; McPherson *et al*., 2016), taboos (Colding & Folke, 2001; Lingard *et al*., 2012), temporary restrictions (Camacho *et al*., 2012; Hammi *et al*., 2010; Khan *et al*., 2014), selective cutting or other small-scale disturbances (Rodenburg *et al*., 2012; Zent & Zent, 2004), and assisted natural regeneration (Camacho *et al*., 2012; also see chapter 2.2 section 2.2.4). As many IPLCs obtain their daily needs from the world's forests (Angelsen *et al*., 2014; TEEB, 2010), habitat loss and degradation often entail loss of subsistence and livelihood for IPLCs. Evidence also shows that policies devolving power to manage natural resources from governments to IPLCs and recognizing IPLCs' land rights may reduce rates of habitat loss (Ceddia & Zepharovich, 2017; Chen *et al*., 2012) and that integrating ILK into conservation initiatives can help to reduce biodiversity loss (Brooks *et al*., 2012).

Aichi Target 6: Managing and sustainably harvesting aquatic living resources

There are no global data on the extent of IPLC areas in the marine realm nor on how inclusion of IPLCs in MPA management affects fisheries. However, ILK has informed fisheries management in many contexts (e.g., McMillen *et al*., 2014; Thornton and Scheer, 2012), including mapping spawning grounds (Ames, 2004, 2007; Ames *et al*., 2000), understanding the structure, ecology and use of seascapes (Williams & Bax, 2003), assessing ecological and socio-economic sustainability of reef fisheries (Teh *et al.,* 2005), and documenting long-term reef fisheries trends (e.g., Daw *et al.,* 2011a; Teh *et al.,* 2007; Tesfamichael *et al.,* 2014). At the species level, fishers' ILK has been used to document long-term changes (Neis *et al.,* 1999; Spens, 2001), describe species' biology and environment (Camirand *et al.,* 2001), and assess species' cultural importance (Leeney & Poncelet, 2013). Studies drawing on IPLCs have also been instrumental in identifying marine fish species that are declining and/or at risk of extinction, and the implications for policy and management (e.g., Dulvy & Polunin, 2004; Lavides *et al.,* 2010, 2016; Maynou *et al.,* 2011; Sadovy & Cheung, 2003) and have helped to assess changes in fish diversity (e.g., Azzurro *et al.,* 2011; Castellanos-Galindo *et al.,* 2011; Saenz-Arroyo *et al.,* 2005a, 2005b). IPLCs have also supported recovery, conservation and sustainability of marine and freshwater fisheries and ecosystems around the world (Begossi, 1998; Berkes *et al.,* 2000; Hanna, 1998; UNDP, 2017). IPLCs have promoted the concept of "nature's rights" that has influenced policy at multiple levels (Burdon, 2012; Gordon, 2017; Mihnea, 2013; Sheehan, 2014). Many IPLCs are highly reliant on marine ecosystems, and especially fisheries, (Cisneros-Montemayor *et al*., 2016; Forest People's Programme, 2016), for which IPLCs are disproportionately affected by unsustainable fishing practices (Cabral & Alino, 2011). Management policies that have tried to address the issue include the UNDP-GEF Equator Initiative (UNDP, 2017) and the Ecotipping Points Project (http://ecotippingpoints.org/index.html).

Aichi Target 7: Managing agriculture, aquaculture and forestry sustainably

IPLCs are important natural resource users and managers and provide many examples of sustainable management systems (e.g., FAO's Globally Important Agricultural Heritage Systems; http://www.fao.org/giahs/en/, see also chapter 2.2 section 2.2.4). Traditional agriculture (Johns *et al*., 2013), aquaculture (Le Gouvello *et al*., 2017; Rose *et al*., 2016), and community forestry initiatives (Gbedomon *et al*., 2016) or other forms of forest conservation (Boadi *et al*., 2017; Negi, 2010) show promise for conserving local biodiversity. Locally controlled resources also provide economic opportunities while incorporating community values (Claire & Segger, 2015; Oldekop *et al*., 2016). With appropriate local oversight and resource use agreements, these practices can help conserve local biodiversity and generate sufficient resources to maintain livelihoods, particularly when in tandem with other sources of income (Barrios *et al*., 2018; Berkes and Davidson-Hunt, 2006; Gbedomon *et al*., 2016). However, IPLC management strategies respond to social and economic pressures, which often encourage unsustainable management of natural resources (Lawler & Bullock, 2017)***.*** Therefore, the sustainability of IPLCs' management practices should not be assumed but requires demonstration and regular monitoring (Montoya & Young, 2013). Economic and environmental policies that effectively promote simultaneous social well-being and conservation of biodiversity are still lacking for most IPLCs (Caillon *et al*., 2017). Interventions aimed at improving access to social services and economic institutions can have greater land-management impacts than those aimed at conservation or resource productivity alone (Bene & Friend, 2011). Effective multiscale governance is still needed to support sustainable economic and subsistence activities such as forestry, agriculture, and both fresh and marine aquaculture (Berkes *et al*., 2000; Forest Peoples Programme, 2011; Nelson & Chomitz, 2011; Ostrom, 1990; Porter-Bolland *et al*., 2012).

Aichi Target 8: Reducing pollution

IPLCs help to limit pollution through the maintenance of traditional agricultural practices with limited use of pesticides and fertilizers (Dublin & Tanaka, 2012; FPP *et al*., 2016). IPLCs' traditional management practices also include remediation techniques (e.g., phytoremediation) to restore landscapes affected by pollution (Pacheco *et al*., 2012; Sandlos & Keeling, 2016; Sistili *et al*., 2006) and contribute to pollution buffering and nutrient cycling (Ulrich *et al*., 2016; Vierros, 2017). Additionally, local observations and ILK often enable IPLCs to monitor, map and report the expansion of pollution, e.g., in water bodies (Bradford *et al*., 2017; Rosell-Melé *et al*., 2018; Sardarli, 2013). IPLCs are often disproportionally affected by the impacts of pollution, because they rely on their immediate environments (e.g., water streams, local resources) for meeting their direct livelihood needs (Nguyen *et al*., 2009; Orta-Martínez *et al*., 2017; Suk *et al*., 2004). Pollution not only directly affects the health and well-being of many IPLCs (Dudley *et al*., 2015; Gracey & King, 2009; Valera *et al*., 2011), but also their cultural integrity (Pufall *et al*., 2011; Tian *et al*., 2011). Exposure of IPLCs to pollution often comes through the consumption of traditional wild foods (Curren *et al*., 2014; Russell *et al*., 2015; Ullah *et al*., 2016). The pollutants to which IPLCs are most often exposed include heavy metals such as mercury (e.g., Lyver *et al*., 2017), lead (Udechukwu *et al*., 2015), arsenic (Sandlos & Keeling, 2016), and zinc (Ullah *et al*., 2016), as well as DDT (Reyes *et al*., 2015) and high levels of radiation (van Dam *et al*., 2002; Williams *et al*., 2017). Given this, IPLCs worldwide are engaging in community-based participatory monitoring of pollution and ecosystem health (Benyei *et al*., 2017; Deutsch *et al*., 2001; McOliver *et al*., 2015). There is well-established evidence of IPLCs' organized resistance against polluting activities, e.g., oil extraction (Orta-Martínez & Finer, 2010; Temper *et al*., 2015; Veltmeyer & Bowles, 2014), including litigation to hold polluters accountable (Benyei *et al*., 2017; Martínez-Alier *et al*., 2010, 2014, 2016; Petherick, 2011). However, the contributions of IPLCs to the prevention and reduction of pollution are seldom recognized. With few exceptions (e.g., Lyons, 2004; O'Faircheallaigh 2013), IPLCs remain largely unsupported in their legal battles against polluting corporations operating in IPLC territories (MacDonald 2015; Rodríguez Goyes *et al*., 2017). As such, they often face enormous challenges in receiving compensation for the impacts of pollution (Koh *et al*., 2017; Martínez-Alier, 2014).

Aichi Target 9: Preventing, control and eradicating invasive alien species

There are many examples of IPLCs' contributions to invasive alien species (IAS) management, control, monitoring and eradication (Bart, 2010; Bart & Simon, 2013; Fredrickson *et al*., 2006). The role of IPLCs in monitoring IAS has been documented in a range of ecosystems (e.g., (Jevon & Shackleton, 2015; Luizza *et al*., 2016; Santo *et al*., 2017; Schüttler *et al*., 2011; Sundaram *et al*., 2012; Uprety *et al*., 2012; Voggesser *et al*., 2013), including invasive fishes (e.g., Aigo & Ladio, 2016; Azzurro & Bariche, 2017) and crabs (e.g., Cosham *et al*., 2016) in marine environments, invasive plants in coastal wetlands (Bart, 2006), and invasive insects in North America (Costanza *et al*., 2017). IPLCs are directly affected by the spread of IAS through impacts on food production, water sources, time and resource loss, or damage to sacred areas (Duenn *et al*., 2017; Rai & Scarborough, 2015; Shackleton *et al*., 2007; Turbelin *et al*., 2017). However, IAS may also be integrated into IPLCs' subsistence strategies (Hall, 2009; Sato, 2013) and pharmacopeia (Philander, 2011; Srithi *et al*., 2017), given that IPLCs may not regard all IAS as 'weeds' or 'pests' (Trigger, 2008), with implications for IAS management practices (Bach & Larson, 2017), especially if IPLCs are involved in co-designing IAS-control experiments and management strategies (Ens *et al*., 2016a).

Aichi Target 10: Minimizing pressures on ecosystems vulnerable to climate change

There is clear evidence that IPLCs have contributed substantially to the management and conservation of areas particularly sensitive to climate change, such as the Arctic (Johnson *et al*., 2015), coastal wetlands, mangroves, and seagrass beds (Aburto-Oropeza *et al*., 2011; Moshy & Bryceson, 2016; Teixeira *et al*., 2013), especially when they contribute to the design of management plans (Vierros, 2017). Given that top-down marine protected areas management strategies have often excluded collaboration with IPLCs (Moshy & Bryceson, 2016; van Putten *et al*., 2016; Vaughan & Caldwell, 2015), co-management has emerged as an alternative bottom-up approach that may be beneficial for resource and landscape-seascape conservation (Aburto-Oropeza *et al*., 2011; Datt & Deb, 2017; Siregar *et al*., 2016; Vaughan & Caldwell, 2015). IPLCs have been foundational in recognizing and protecting the links between land and sea management in the coastal zones (Haggan *et al*., 2007; Johannes, 1992; Jupiter *et al*., 2014a). The preservation of the marine natural environment and ILK in coastal zones is essential for some IPLCs' food sovereignty and livelihood (e.g., Inuit Circumpolar Council, 2015; Kronen, 2004). IPLCs have developed particular forms of natural resource management that do not directly seek profit, but social and cultural compensation (Lauer & Aswani, 2009; Walters, 2004). However, increasing monetarization (e.g., through mass tourism on coral reefs or shrimp aquaculture in mangroves) can lead to the loss of sense of social value, with potential implications for ecosystem's health (Arias-González *et al*., 2017). Strenthening self-determination can contribute to improve natural resource management and food sovereignty (Inuit Circumpolar Council, 2015).

Aichi Target 11: Conserving terrestrial and marine areas through protected areas and other area-based measures

There is considerable overlap between global biodiversity hotspots and ancestral IPLCs' homelands (Garnett *et al*., 2018; Guèze *et al*., 2015; Kandzior, 2016; Porter-Bolland *et al*., 2012). Through traditional practices such as taboos, beliefs, or the establishment of sacred site guardians, IPLCs have facilitated the persistence of biodiversity important areas worldwide (Karst, 2017; Lopez-Maldonado & Berkes, 2017; McPherson *et al*., 2016; Samakov and Berkes, 2017). Moreover, IPLCs' biodiversity protection often combines multiple goals and purposes, with spatial and temporal management of species helping to maintain ecosystem function and resilience (Dominguez *et al*., 2010; Elmkvist *et al*., 2004; Ruiz-Mallen & Corbera, 2013). This has often led to the designation of protected areas within IPLCs' lands (Maraud & Guyot, 2016; Mueller *et al*., 2017; Shen *et al*., 2012; Stevens, 2014), often without obtaining the Free, Prior and Informed Consent of IPLCs (e.g., Hermann and Martin, 2016). Moreover, because biodiversity conservation is inherently spatial, displacement of IPLCs from their ancestral lands, restriction of resource access, and changing land use patterns have often been a consequence of conservation projects dominated by ideas to preserve 'wilderness' (Agrawal & Redford, 2009; Samakov & Berkes, 2017; Shultis & Heffner, 2016). This can lead to conflicts (Agrawal & Redford, 2009; Geisler, 2003; Lepetu *et al*., 2009). While c. 40% of protected areas lie on Indigenous Peoples' lands (Garnett *et al*., 2018), <1% of protected areas in the *World Database on Protected Areas* are reported to be governed by IPLCs (UNEP-WCMC & IUCN, 2016). While the percentage might be higher if other forms of protection were considered, it indicates the lack of recognition by governments of IPLCs in the formal system of protected areas. Expansion of protected areas may generate disproportionate costs to IPLCs (e.g., restricting access to hunting or grazing areas). For example, MPA expansion in the Arctic may threaten IPLCs' hunting, particularly if MPAs are planned without consultation. Some areas conserved by IPLCs, such as Indigenous Peoples' and community conserved areas (ICCAs) also contribute to conservation (see Borrini-Feyerabend *et al*., 2004) and therefore may qualify as 'Other effective area-based conservation measures' (OECMs; Jonas *et al*., 2017), although some ICCAs are treated by governments as protected areas, and hence excluded from the definition of OECMs (Jonas *et al*., 2017; UNEP-WCMC & IUCN, 2016). The contribution of ICCAs to biodiversity conservation globally has not been quantified, but the fact that they cover 20% of the total terrestrial surface (Kandzior, 2016) in a wide variety of habitats (Bhagwat & Rutte, 2006) signals their potential for contributing to ecosystem maintenance (Kothari *et al*., 2014). Moreover, safeguarding IPLCs' ownership of knowledge, respecting their laws and principles (Johnson *et al*., 2016), promoting customary management practices, and involving IPLCs as equal partners in research and monitoring may increase the effectiveness of protected areas (Brooks *et al*., 2012; Ens *et al*., 2016b; Holmes *et al*., 2016; Housty *et al*., 2014; Kandzior, 2016; Molnar *et al*., 2016; Moreaux *et al*., 2018).

Aichi Target 12: Preventing extinctions and improving the conservation status of species

The contributions of IPLCs to the conservation of threatened species includes controlling poaching (Lotter & Clark, 2014), reducing other sources of mortality (Gunn *et al*., 2010), maintaining sacred sites (Pungetti *et al*., 2012), food taboos (Colding & Folke, 2001; Jones *et al*., 2008; Pungetti *et al*., 2012), and traditional land management (Bird *et al*., 2013; Ashenafi *et al*., 2012). The number of threatened species conserved by IPLCs has not been quantified, but because IPLCs often live in areas of high biodiversity (Renwick *et al*., 2017; Sobrevila, 2008), they have the capacity to conserve disproportionately high numbers of threatened species (Beckford *et al*., 2010; Takeuchi *et al*., 2017). Culturally important threatened species conserved by IPLCs include salmon (Ween & Colombi, 2013), wolves (Ohlson *et al*., 2008), vicuñas (Arzamendia & Vila, 2014), polar bear and walrus (Meek *et al*., 2008). Such efforts may conflict with non-indigenous land owners and managers (Breslow, 2014; Findlay *et al*., 2009) and some IPLCs have to defend their rights to participate in threatened species conservation (Muir & Booth, 2012; Olive, 2012; Olive & Rabe, 2016), and the values they bring to that practice (Nadasdy, 2006). A recent assessment in Australia found that at least 59.5% of Australia's threatened species occur on Indigenous Peoples' lands (Leiper *et al*., 2018). Progress is also being made in conserving species that pose risks to humans and crops (Dolrenry *et al*., 2016; Larson *et al*., 2016; Rastogi *et al*., 2012). IPLC skills and knowledge can be used to help into threatened species' conservation (Attum *et al*., 2008; Dolrenry *et al*., 2016) and management (Gilchrist *et al*., 2005; McPherson *et al*., 2016; Vongraven *et al*., 2012). Threatened species are often culturally significant to IPLCs, and their decline impact IPLCs' diet, medicine, and other aspects (Chiropolos, 1994; Poufoun *et al*., 2016). For example, when India's vulture populations crashed (Prakash *et al*., 2003), the Parsee people were forced to develop new ways to dispose of the bodies of their dead (van Dooren, 2010). Successful recovery of threatened species may not only improve ecosystem conditions (Bottom *et al*., 2009), but also invigorate IPLCs' culture and economy (Coria & Calfucura, 2012; Hamilton *et al*., 2011; Humavindu & Stage, 2015; Yagi *et al*., 2010). However, not all cases of IPLCs' use of native species is sustainable, and some may negatively impact threatened species (e.g., Frith & Beehler, 1998; Mack & Wright, 1998).

Aichi Target 13: Maintaining the genetic diversity of cultivated plants, domesticated animals and wild relatives

It is well established that IPLCs have contributed to enhancing the genetic diversity of crops (Brush, 2000, 2004; Gepts *et al*., 2012) and domesticated animals (Yaro *et al*., 2017) through species domestication (Khoury *et al*., 2016), diffusion (Roullier *et al*., 2013) and management (Brush, 2000; Salick, 2012). IPLCs have also contributed to the in-situ conservation of such diversity (e.g., Galluzzi *et al*., 2010; Perrault-Archambault & Coomes, 2008; Thomas & Caillon, 2016; see also chapter 2.2 section 2.2.4). IPLCs have developed strategies to minimize genetic erosion through local systems that promote seed maintenance and flow (through market and non-market seeds exchanges) (Calvet-Mir & Salpeteur, 2016; Nazarea, 2006; Thomas & Caillon, 2016). Although initiatives that value IPLCs' contributions to *in situ* conservation of genetic diversity can be found worldwide (e.g., Graddy, 2013; Wilkes, 2007), IPLCs' ability to contribute further to safeguard genetic diversity is limited by the loss of knowledge, migration to cities, undervaluation of local management practices by some agricultural extension programs (Jacobi *et al*., 2017), legislation adverse to the rights to save and exchange seeds (Deibel, 2013), and the introduction of improved mass propagation methods (Jaradat, 2016) and hybrid or genetically modified seeds (e.g., (Shewayrga *et al*., 2008). *In situ* conservation and use of crop genetic resources is of prime importance for IPLCs' food security (Johns & Eyzaguirre, 2006), as it allows long-term access to locally adapted seed and planting material (Finetto, 2010; Maxted *et al*., 2002). Traditional breeds of grazing livestock (and related traditional practices) are key for managing some high biodiversity grasslands in protected areas (Kis *et al*., 2017).

Aichi Target 14: Restoring and safeguarding ecosystems that provide essential services

IPLCs have a key role in restoring and safeguarding the world's ecosystems. While not all the lands managed by IPLCs are intact, multiple examples from around the world show that, when carefully implemented with close involvement from well-organized communities, devolving control of resource management to IPLCs can produce better outcomes for conservation and ecosystem service provision than private management, and in some cases, even than strict protected areas (Bray *et al*., 2008; Chhatre & Agrawal, 2009; Paudyal *et al*., 2017; Persha *et al*., 2011; Poteete & Ostrom, 2004). IPLCs have also played an active role in restoring ecosystems to produce ecosystem services essential to human well-being (Anderson & Barbour, 2003; FAO 2015b, Hansson, 2001; Madrigal Cordero *et al*., 2012; Wilson and Rhemtulla, 2016; Wilson *et al*., 2017). IPLCs can increase the effectiveness of ecosystem restoration activities (Senos *et al*., 2006; Uprety *et al*., 2012) because they know the land and can directly benefit from restoration activities (Babai & Molnár, 2014; Schaffer, 2010; Wangpakapattanawong *et al*., 2010). For example, in the Maradi and Zinder Regions of Niger, local communities 're-greened' over five million hectares of land through farmer-managed natural regeneration, which helped reverse desertification and produced other services important for farming (Reij & Garrity, 2016; Sendzimir *et al*., 2011). Moreover, modern restoration activities increasingly involve ILPCs and make use of ILK (Marsden-Smedley & Kirkpatrick, 2000; Middleton, 2001; NOAA, 2017; Senos *et al*., 2006; Shebitz, 2005; Storm & Shebitz, 2006). Lack of progress towards this target has had serious implications for IPLCs, as they are often relatively reliant on shared or communal natural resources, such as forests (Almeida, 1996; Angelsen *et al*., 2014; Godoy *et al*., 2000). Thus, loss of access to or degradation of natural resources have a disproportionately negative effect on IPLCs (Seaman *et al*., 2014), often resulting in migration to urban areas (e.g., Alexiades & Peluso, 2015). As they often lack formal land rights, IPLCs may receive little formal recognition for environmental goods and services produced on their lands and may be unable to access specialized markets (Ollerer *et al*., 2017; Oxfam *et al*., 2016; RRI, 2015). Furthermore, remote or impoverished conditions, weak governance structures, or a lack of representation can all limit participation in programs to compensate producers of local ecosystem services (Bark *et al*., 2015; Benjamin & Blum, 2015; Zbinden and Lee, 2005).

Aichi Target 15: Enhancing ecosystem resilience and the contribution of biodiversity to carbon stocks through conservation and restoration

Through their natural resource management systems, IPLCs have contributed to conservation of carbon stocks and strengthened ecosystem resilience (FPP *et al*., 2016; Mijatović *et al*., 2012; Nakashima *et al*., 2012; Uprety *et al*., 2012; Wangpakapattanawong *et al*., 2010; see also chapter 2.2 section 2.2.4). This is because IPLCs' land management regimes tend to have lower deforestation rates than surrounding areas, thus avoiding carbon emissions and preserving other NCP (Paneque-Gálvez *et al*., 2013; RAISG, 2016; Ricketts *et al*., 2010; Schleicher *et al*., 2017; Vergara-Asenjo & Potvin, 2014). IPLCs' lands in the Amazon Basin, Mesoamerica, the Democratic Republic of Congo and Indonesia contain over 20% of the above-ground carbon in all the world's tropical forests (Walker *et al*., 2014). ILK-based land management practices are effective at enhancing carbon sequestration, preventing environmental degradation and combatting desertification (e.g., Cheng *et al*., 2011; Chirwa *et al*., 2017; Salick *et al*., 2014; Seid *et al*., 2016; Singh *et al*., 2014; Wangpakapattanawong *et al*., 2010). IPLCs' practices of soil carbon enrichment are well recognized in Amazonia (Glaser, 2007; Junqueira *et al*., 2010, 2016; Lehmann *et al*., 2003). Similarly, IPLC fire management regimes contribute substantially to greenhouse gas abatement and ecosystem resilience (Shaffer, 2010; Welch *et al*., 2013; Wilman, 2015). There is also well-established evidence of the crucial role that IPLCs play in ecological restoration efforts that help build social-ecological resilience (Egan *et al*., 2011; Kimmerer, 2000; Lyver *et al*., 2016; Storm *et al*., 2006; Wehi & Lord, 2017), although the percentage of restoration efforts globally that are currently led by or involve IPLCs is unknown. Engagement of IPLCs in community forestry has been shown to be a useful model for restoration of degraded forests (Maikhuri *et al*., 1997; Paudyal *et al*., 2015), while co-management has shown mixed success in other ecosystems (der Knaap, 2013; Hill & Coomes, 2004). IPLCs are key participants in several large-scale forest restoration efforts, particularly in Asia (Bennett, 2008; Clement *et al*., 2009; He & Lang, 2015; McElwee, 2009; Yan-qiong *et al*., 2003).

Safeguarding ecosystem resilience is critical to promote IPLCs' quality of life (Caillon *et al*., 2017; Kingsley & Thomas, 2017; Sangha *et al*., 2015; Sterling *et al*., 2017). The failure to restore degraded ecosystems in areas inhabited by IPLCs threatens their cultural well-being, undermining access to important NCP (Adger *et al*., 2005; Aronson *et al*., 2016; FPP *et al*., 2016; Golden *et al*., 2016). Where ecological restoration is participatory and attuned to local socioeconomic benefits, IPLCs gain increased access to NCP and conflicts are reduced (Baker, 2017; Gobster

& Barro, 2000; Shackelford *et al*., 2013; Wortley *et al*., 2013). Recognizing the customary institutions of IPLCs is a critical means for connecting IPLCs with policies promoting ecosystem restoration and carbon compensation schemes (Buntaine *et al*., 2015; Larson *et al*., 2013; Sunderlin *et al*., 2014). Specifically, land titles to forest can provide access to incentive programs that pay for the maintenance of forest cover (Duchelle *et al*., 2014b; Larson, 2010; Turnhout *et al*., 2017; van Dam, 2011). Overall, property rights, land availability, social organization and political networks constitute key factors for IPLCs in accessing and benefiting from carbon offsets (Boyd *et al*., 2007; Corbera & Brown, 2010; Kerr *et al*., 2006; Osborne, 2011). Current carbon forest standards have shown moderate success in protecting IPLC rights (De La Fuente & Hajjar, 2013; Larson, 2011; McDermott *et al*., 2012; Roe *et al*., 2013). Because many carbon compensation schemes intersect with IPLC sociocultural values, active involvement of IPLCs in policy design has been found to be essential for success, particularly in building partnerships and avoiding value conflicts (Davenport *et al*., 2010; Fox *et al*., 2017; Lawlor *et al*., 2010; Lyver *et al*., 2016; Richardson & Lefroy, 2016; Rose *et al*., 2016).

Aichi Target 16: Operationalizing the Nagoya Protocol on Access and Benefit-Sharing

IPLCs have contributed to the establishment of research protocols and procedures (e.g., Consortium of European Taxonomic Facilities, 2015) and they have played an important role in negotiating the Nagoya Protocol on Access and Benefit-Sharing (GEF, 2015a; Teran, 2016). The potential effects of the protocol have been assessed (Atanasov *et al*., 2015; Burton & Evans-Illige, 2014; Nijar *et al*., 2017; Rose *et al*., 2012; Welch *et al*., 2013), and a number of countries are supporting capacity-building efforts to develop community protocols to facilitate the development of Access and Benefit-Sharing arrangements with potential users of traditional knowledge associated with genetic resources (Pauchard, 2017). However, IPLCs' contributions to bring the protocol in force in national legislation are poorly documented (Robinson & Forsyth, 2015; Sanbar, 2015). The implementation of the Nagoya Protocol and the broader participation of IPLCs in research and resource management have also contributed to a shift in research practice that has been recognized at institutional (Balick, 2016), national (Bendix *et al*., 2013), and international levels (Bussmann, 2013; Bussmann & Sharon, 2014). Such a shift involves a growing recognition of IPLCs' rights to fully informed prior consent, participation in research at all levels, including authorship, and right to benefit from commercial use of research results.

Aichi Target 17: Developing and implementing national biodiversity strategies and action plans

There is clear consensus that inclusion of ILK may enhance NBSAPs (Ayesegul and Jones-Walters, 2011; Armatas *et al*., 2016; Gadamus *et al*., 2015; Sutherland *et al*., 2013; Tengö *et al*., 2014), yet these inputs are still scarce. For example, in a review of the conservation literature, Brook and McLachlan (2008) found that only about 0.4% of conservation plans included ILK. Less than half of countries reported ecological, management, regulatory or policy information on the importance of ILK and practices in the management of wild populations and near-natural ecosystems (see also FPP *et al*., 2016). In addition, only 20 CBD Parties reported the involvement of IPLCs in their NBSAPs (18%), indicating that few Parties have developed adequate participatory approaches (Adenle *et al*., 2015). Barriers to ILK inclusion into conservation plans include bridging epistemological differences between knowledge systems (Löfmarck and Lidskog, 2017), low academic recognition of ILK (Farwig *et al*., 2017), and issues of scale and power (Beck *et al*., 2017). The impact of achieving this target on IPLCs is largely dependent on land management arrangements: where the land is co-managed and ILK is incorporated into management plans, IPLCs are often positively impacted and conservation efforts are greatly improved (Berkes, 2018; Berkes *et al*., 1995; Borrini-Feyerabend *et al*., 2004; Gadgil *et al*., 2000; Rozzi *et al*., 2006). Unfortunately, the engagement of IPLCs in NBSAPs is not yet receiving sufficient attention. The extent to which IPLCs are recognized, valued, and benefit from contributing to the target is difficult to assess (Marques *et al*., 2016). The retroactive inclusion of IPLCs into an existing biodiversity plan can highlight inequities and instances where the plans have been detrimental to IPLCs (Galbraith *et al*., 2017). Conversely, the recognition of the value of ILK and the inclusion of IPLCs in the formulation of management plans can greatly benefit them (Chen & Nakamura, 2016; Shimada, 2015).

Aichi Target 18: Respecting and integrating traditional knowledge and customary sustainable use

Consideration of ILK relevance for conservation has increased since the 1980s, driven by research highlighting the potential value of ILK for sustainable resource use and biodiversity conservation (Berkes *et al*., 2000; Brokensha *et al*., 1981; Warent *et al*., 1995), the trans-nationalization of the indigenous rights movement (Benyei *et al*., 2017; Reyes-Garcia, 2015), and the realization that biological and cultural erosion could be intertwined (Maffi, 2005; Zent, 2009a; Zent & Zent, 2007). The importance of integrating ILK into biodiversity conservation efforts was first acknowledged at the 1992 CBD Conference of the Parties (Reyes-García, 2015) and has grown since then (e.g., Apostolopoulou *et al*., 2012; Cheveau *et al*., 2008; Daniels *et al*., 1993; Ferroni *et al*., 2015; Hernandez-Morcillo *et al*., 2014; Marie *et al*., 2009; Sekhar, 2004; Sibanda & Omwega, 1996; Vaz & Agama, 2013). Integrating ILK into conservation efforts in a participatory way can not only improve the local acceptance of conservation initiatives (Andrade & Rhodes, 2012; Carpenter, 1998; Grainger, 2003), but also benefit IPLCs by adding value to ILK, raising local awareness of this value, and therefore mitigating ILK erosion, strengthening IPLCs' collective action capacity, land/resource rights, health, religious freedom, self-determination, intangible heritage protection, and control over how ILK is used (Baral & Stern, 2010; Chitakira *et al*., 2012; Cil & Jones-Walters, 2011; Reyes-Garcia, 2015). Integrating ILK into conservation initiatives has been achieved through a variety of top-down approaches (e.g., Integrated Conservation-Development Projects and Participatory Monitoring Projects; Berkes, 2007; Danielsen *et al*., 2000; Hanks, 2003; Joseph, 1997; Ruiz-Mallén & Corbera, 2013; Sanjayan *et al*., 1997), with researchers and IPLCs contesting the real "participatory" nature of some of these approaches (e.g., Dressler *et al*., 2010; Khadka & Nepal, 2010; Sterling *et al*., 2017) and the real benefits for IPLCs and for conservation itself (Büscher *et al*., 2017; Nadasdy, 1999a; West, 2006). IPLCs have also led conservation and ILK revitalization initiatives, such as establishing Indigenous and Community Conserved Areas (ICCAs), maintaining sacred natural sites, language and cultural documentation, or community-based mapping (Alexander *et al*., 2016; Berdej & Armitage, 2016; Brooks *et al*., 2013; Gavin *et al*., 2015; Kothari *et al*., 2013; Nelson, 2008; Nilsson *et al*., 2016; Zent *et al*., 2016). Through these initiatives, IPLCs, in alliance with advocacy groups, have enhanced their role as environmental managers and transformed their local disputes into international claims, thus increasing pressure to be included in environmental policy for a (Hodgson, 2002) and propelling a growing recognition of ILK in environmental negotiations (Nasiritousi *et al*., 2016; Schroeder, 2010; Tengö *et al*., 2014; Wallbott, 2014). Despite these moves, IPLCs typically continue to remain politically marginalized parties in their own countries and even more so on the global stage (Corson, 2012), and are often dependant on opportunities provided by policymakers or project-designers for participation (Harada, 2003).

Aichi Target 19: Improving, sharing and applying knowledge of biodiversity

There is increasing technological cross-fertilization involving IPLCs' biodiversity-sustaining technology and knowledge being adopted and adapted to wider use and vice versa (Berkes *et al*., 2000; Jasmine *et al*., 2016; Lynch *et al*., 2010; Varga *et al*., 2017). Recent examples of technology and knowledge sharing include the use of drones (Paneque-Galvez *et al*., 2017), community mapping (Assumma & Ventura, 2014; Heckenberg, 2016) and counter-mapping (McLain *et al*., 2017), cloud computing (Valencia Perez *et al*., 2015) and other information and communication technology applications for local biodiversity conservation (Bazilchuk, 2008; Coleman, 2015), such as citizen science and knowledge network initiatives (Bortolotto *et al*., 2017; Wyndham *et al*., 2016) and projects to return control over biodiversity to heritage owners (Bolhassan *et al*., 2014; Cairney *et al*., 2017; Thompson, 1999). IPLCs' education systems and traditional institutions for knowledge transfer are also beginning to be valued in conservation research and policy (Kawharu *et al*., 2017; Walsh *et al*., 2013; Wuryaningrat *et al*., 2017), as is the value of diversity in knowledge systems, including gender (Fillmore *et al*., 2014; Wirf *et al*., 2008), age-class (Bayne *et al*., 2015), and intra- (Saynes-Vasquez *et al*., 2016) and inter-cultural diversity (Reyes-García *et al*., 2016a). The literature on IPLCs and biodiversity knowledge shows that ideology (Gorman & Vemuri, 2012; Oviedo & Puschkarsky, 2012), social organization (Elands *et al*., 2015), cultural/spiritual values (Daye & Healey, 2015; Oleson *et al*., 2015; Thondhlana & Shackleton, 2015), politics (Wartmann *et al*., 2016), local language, subsistence practices (Zent 2009b, Zhao *et al*., 2016a), and ontology (Clarke, 2016) play a significant part in structuring local ecological relations. IPLCs are particularly vulnerable to lack of progress towards Aichi 19 in that their economies and identities are often inextricably connected to local landscapes and waterscapes (Fox *et al*., 2017) and they have been historically disadvantaged in terms of information access and equal participation in decision-making (Smith, 1999; Turner *et al*., 2008). Decolonization in curricula, museums, and libraries are steps towards reducing historical power-information imbalances (Ladio & Molares, 2013; Pulla, 2017; Zolotareva, 2015). Recognizing and valuing ILK systems, biodiversity conservation practices, and transparent information and power-sharing can strengthen sustainable local food production systems (Kamal *et al*., 2015; Turner & Turner, 2007; Turreira *et al*., 2015), secure land tenure, health and well-being (Catarino *et al*., 2016; Lah *et al*., 2015; Phondani *et al*., 2013), and ecological resilience (do Vale *et al*., 2007; Leonard *et al*., 2013), thus contributing to recognize Indigenous Peoples' rights to self-determination. The valuation of biodiversity in an ecosystem services paradigm is beginning to include more local cultural values (Afentina *et al*., 2017; Sangha & Russell-Smith, 2017) and identify problems created for IPLCs (Preece *et al*., 2016). Involvement of IPLCs in environmental impact assessments (Nakamura, 2008), species management (Gichuki & Terer, 2001; Housty *et al*., 2014) and land management (Flood and McAvoy 2007; Harmsworth *et al*., 2016; LaFlamme 2007; Molnar *et al*., 2016) are increasingly standard practice.

Aichi Target 20: Increasing financial resources for implementing the Strategic Plan for Biodiversity

It is difficult for IPLCs to access the financial mechanisms established to support actions towards achieving the Aichi Biodiversity Targets (FPP *et al*., 2016). The Global Environment Facility (GEF) has supported 160 full- and medium-size projects involving IPLCs (FPP *et al*., 2016). However, despite an overall positive trend (CBD, 2016e), in 2015 only about 15% of the GEF Small Grants Programme (GEF-SGP), a scheme which specifically enables GEF to partner with IPLCs (GEF, 2015b), involved IPLCs. Of the US$4.2 billion that were disbursed by the GEF between 1991 and 2014, only US$228 million have been financed to IPLCs (CBD, 2016e). The contribution of IPLCs' collective action towards achieving the Aichi Biodiversity Targets is included in the Strategy for Resource Mobilization (CBD, 2012b). Furthermore, a methodology for measuring the contribution of IPLCs' collective action has been developed (CBD, 2014a), offering tools to assess contributions both quantitatively (e.g., impact on environmental change rates, extent, direction) and qualitatively (e.g., impact of formal and informal rules regarding resource use and management; CBD, 2014b). Local initiatives are often highly cost-effective while their outcomes often meet multiple policy objectives, including community development, biodiversity conservation and cultural well-being (CBD 2014b).

3.3 IMPACTS OF TRENDS IN NATURE ON PROGRESS TOWARDS THE SUSTAINABLE DEVELOPMENT GOALS

3.3.1 Introduction to an integrated assessment approach

In order to assess how trends in nature and NCP affect our ability to achieve the SDGs, and how SDG achievement impacts on nature and NCP, we developed an integrated approach that takes into account the complex relationships between nature and the SDGs, as well as limitations in the current articulation of SDG targets. Despite overwhelming evidence of the linkages between nature, NCP and development, the current focus and wording of most SDG targets obscures or omits their relationship to nature or NCP. For example, the role of nature in targets for SDGs 1, 3, 8 and 9 is largely absent or the SDG targets are too narrowly defined for proper consideration of the roles of

Table 3 5 **Clusters used to guide the assessment of SDG progress linked to nature and NCP.**

Clusters are based on the nature of the relationships and feedbacks between SDGs, nature and NCP. The names of each cluster are drawn from the IPBES conceptual framework to illustrate the focus of the SDGs in each cluster. Clusters also differed in terms of the level of assessment possible (goal vs. target) due to current target formulations and available data and were subjected to different types of approaches in the assessment.

Cluster	SDGs	Assessment approach	Targets assessed
Nature	6 CLEAN WATER AND SANITATION; 13 CLIMATE ACTION; 14 LIFE BELOW WATER; 15 LIFE ON LAND	Target-level assessment using indicators and evidence of trends in nature	1.1; 1.2; 1.4; 1.5; 2.1; 2.3; 2.4; 2.5 3.2; 3.3; 3.4; 3.9 11.4; 11.5; 11.6; 11.7
Nature's contribution to people (NCP)	1 NO POVERTY; 2 ZERO HUNGER; 3 GOOD HEALTH AND WELL-BEING; 11 SUSTAINABLE CITIES AND COMMUNITIES	Target-level assessment presenting evidence of links between nature, NCP and targets, and assessing trends in relevant NCP using indicators and evidence	6.3; 6.4; 6.5; 6.6 13.1; 13.2; 13.3; 13.A; 13.B 14.1-14.7 15.1-15.9; 15.A; 15.B
Good quality of life (GQL)	4 QUALITY EDUCATION; 5 GENDER EQUALITY; 10 REDUCED INEQUALITIES; 16 PEACE, JUSTICE AND STRONG INSTITUTIONS	Goal-level assessment presenting evidence of links between nature, NCP and goal	
Drivers of change in nature and NCP	7 AFFORDABLE AND CLEAN ENERGY; 8 DECENT WORK AND ECONOMIC GROWTH; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Goal-level assessment presenting evidence of links between nature, NCP and goal	

nature and NCP (Pérez & Schultz, 2015). In an attempt to address these gaps, we used a clustering approach to SDG progress assessment, focusing on SDGs for which detailed target-level assessment of trends is possible because there are targets that directly link to aspects of nature or NCP (Cluster 1, 2; **Table 3.5**). For SDGs with targets that do not explicitly recognize the links with nature and NCP, we limit our assessment to a synthesis of the evidence of these links at a goal in order to suggest directions for future assessments (Clusters 3, 4; **Table 3.5**).

These clusters are further differentiated to acknowledge the many different relationships between nature and the SDGs (Guerry *et al*., 2015). We identified clusters of: goals with direct positive linkages between nature and SDGs (Cluster 1; Nature); goals with complex (direct, indirect, positive and negative) relationships and feedbacks between NCP and SDGs (Clusters 2; NCP), goals with some evidence of complex linkages with nature and NCP, but for which current knowledge and focus or wording of SDG targets prevents trend assessment (Cluster 3; GQL); and goals for which meeting SDG targets may have potential positive or negative feedbacks on nature and NCP (Clusters 4; Drivers). The cluster methodology is described below together with the assessment approach adopted for each cluster **(Table 3.5)**.

Cluster 1: Nature: SDGs for which there is a direct and positive relationship between nature and our ability to meet SDG targets: Goal 14 (Life below water), Goal 15 (Life on land) and aspects of Goal 6 (Clean water and sanitation). These goals focus on conserving and/or the sustainable use of nature and natural resources (or NCP) in various ecosystems. Goal 13 (Climate action), while not specifically mentioning nature, includes specific targets for combating climate change and its impacts, which have clear positive synergies with nature. In this cluster, there is a direct and typically fairly simple positive relationship, allowing us to assess trends in nature and its contributions to people relevant to these targets through the use of existing indicators, data and literature reviews. We assess all targets in Goals 14 and 15, and those targets with direct links to nature for Goals 6 and 13 **(Table 3.5)**. For each of these targets, we assess progress towards achieving them based on extrapolations to 2030 for relevant indicators, including those in the SDG Indicators Global Database (https://unstats.un.org/sdgs/indicators/database/) as well as other relevant indicators **(Table 3.7)**.

Cluster 2: NCP: SDGs for which there are complex linkages between nature, and its various contributions (material, non-material and regulating) to these SDGs targets. These relationships can be both positive and negative, thereby supporting or undermining SDG target achievement. Furthermore, we recognise that in addition to nature, anthropogenic factors including infrastructure, tenure, skills, technology, are essential to the achievement of these goals. Diaz *et al*. emphasises the co-produced nature of NCP and GQL which is key to achieving the goals in this cluster: Goal 1 (No poverty), Goal 2 (Zero hunger); Goal 3 (Good health and well-being) and Goal 11 (Sustainable cities and communities). This can make understanding and interpreting the effects of trends in nature on these goals and their achievement difficult. We therefore follow a two-phase approach to the assessment of trends in this cluster by first assessing current evidence and knowledge on the features and processes in nature relevant to these targets, and then assessing trends to targets in Goals, 1, 2, 3 and 11, in which clear links to aspects of NCP are present in current expressions of targets. Where available, we examine trends in key indicators for these SDGs (drawing on those used for assessment of progress towards the Aichi Biodiversity Targets in section 3.2). Several targets were omitted because their wording or focus does not provide clear links to NCP. We also note that approaches to achieving these SDGs will have substantial implications for nature and NCP. These impacts could be positive or negative depending on the approach used and will involve feedbacks across scales and time. We highlight evidence of these impacts where possible in our assessment.

Cluster 3: GQL: SDGs associated with GQL that feature goal-level but often complex relationships between the goal and nature. Knowledge about these linkages is currently weak but growing and will be key for future assessments and iterations of these targets. Goal 4 (Quality education), Goal 5 (Gender equality), Goal 10 (Reduce inequalities) and Goal 16 (Peace and justice) do not currently have targets that clearly link to elements of nature or NCP. We therefore do not conduct a detailed assessment of these SDGs in this chapter, but rather conduct a goal-level assessment of the evidence on aspects of nature relevant to these goals

Cluster 4: Drivers: SDGs for which the way we aim to meet the goal will have important implications for nature and NCP. Goal 7 (Affordable and clean energy) Goal 8 (Decent work and economic growth) and Goal 9 (Industry, innovation and infrastructure) in the past have had large negative impacts on nature, NCP and GQL for certain people and places. Goal 12 (Responsible consumption and production) holds particular relevance for future trends of nature and NCP. The outcomes of these goals will be nuanced by positive and negative feedbacks between SDGs operating over space and time. Some paths to achieving a given SDG may have negative implications for other SDGs, while others may have positive impacts. Similarly, certain approaches to achieving SDGs may have positive outcomes in some regions and negative outcomes in others. Further research is needed on how particular approaches to each SDG will influence nature and its contributions to people, and how this is likely to vary in different locations. Chapter 5 explores these pathways and outcomes in more detail. Here we focus on a goal-level assessment, due to a lack of clear linkages with current targets. Where relevant, we also suggest consulting chapter 2 for more details on these drivers of change and their trends.

Based on the clustering approach, we assessed trends in nature and NCP relevant to 44 SDG targets that have clear and well-evidenced linkages to nature and NCP. The SDGs are relatively new (Sustainable Development Platform, 2014), so determining the appropriate indicators for assessing how the status and trends of nature and NCP affect and will be affected by achieving those goals is still a major research effort, as is the indicator development for assessing progress to SDGs at national and global levels. In addition, local priorities or values may differ from the globally chosen indicators. Several goals have indicators identified, but global data are largely incomplete or not available to determine the status and trends in nature and NCP in meeting them. For several targets, the official SDG indicators do not adequately capture the role of nature and NCP in achieving targets. We made use of other available global indicators where possible, and complemented indicator-based assessments with literature reviews to assess the current evidence.

Below we present the findings for selected targets per goal under Clusters 1 and 2 and provide goal-level assessments for Clusters 3 and 4. We summarise the results in **Figure 3.13**.

3.3.2 Assessment findings

3.3.2.1 Cluster 1: Nature (Goals 6, 13, 14, 15)

SDG 6. Clean water and sanitation

The relationship of N and NCP with SDG 6 is direct as well as being synergistic. Achieving SDG 6 will improve water quality and quantity, thus directly benefiting many aspects of N and NCP. Likewise, natural or semi-natural freshwater ecosystems offer valuable contributions towards achieving SDG 6. Over half of global river discharge and the aquatic habitat it supports is under moderate to high threat (Vorosmarty *et al*. 2010). This is driven by deterioration of water quality and over-abstraction of water resources, which severely impact the ability of freshwater ecosystems to regulate water flows, purify water and prevent erosion. In addition, achievement of targets under SDG6 directly affect targets under SDGs 1-3, 11, 14, and 15.

Target 6.3: By 2030, improve water quality by reducing pollution, eliminating, dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.

Water pollution has continued to worsen over the last two decades (UNEP 2016a) and is expected to escalate in the future (IFPRI & Veolia, 2015), causing increased threats to freshwater ecosystems, human health and sustainable development. Trends in three commonly measured pollution indicators are discussed below.

Untreated wastewater pollution is a key driver of deteriorating water quality (WWAP, 2017). On average, high-income countries treat about 70% of the municipal and industrial wastewater they generate. The proportion drops to 38% in upper middle-income countries and 28% in lower middle-income countries. In low-income countries, only 8% undergoes treatment of any kind (Sato *et al*., 2013). These figures explain the often-cited estimate that over 80% of wastewater globally is released to the environment without adequate treatment (WWAP, 2012). This is also supported by combined data and model-driven approaches that show substantial increases in the fecal coliform bacteria loadings in Latin America, Africa and Asia over the last two decades, with an estimated average 80% increase across these three continents (UNEP, 2016a). Although sanitation coverage has increased, and treatment levels have improved in some countries (UNICEF, 2014), the efforts being made have not been sufficient to reduce fecal coliform loadings in surface waters.

Organic pollution in the water is often measured using biochemical oxygen demand (BOD), nitrogen (N) and phosphorus (P) loads. BOD estimates the amount of dissolved oxygen required by microorganisms in the water to break down organic material. High BOD loads reduce dissolved oxygen levels in the river, and negatively impact freshwater fisheries and aquatic ecosystems integrity. High N and P loads can indicate organic pollution levels that risk eutrophication. Eutrophication is the addition of enough nutrients to an ecosystem to cause certain plant species such as algae to proliferate, which can lead to fish deaths because algae deplete the water of oxygen. This can lead to economic hardship for those people depending on inland fisheries and other nature and its contributions to people. Since the 1990s, organic water pollution has increased in over 50% of rivers in South America, Africa and Asia, driven largely by poor wastewater treatment (WWAP, 2017). Some positive trends are evidenced in developed regions, such as steady decline in organic pollution loads in Europe (1992–2012) (EEA, 2015), but positive trends are offset by rapid water quality degradation in developing countries, with an estimated 10–50% increase in the global average nutrient load by 2050 (IFPRI & Veolia, 2015). Increased global BOD, N, and P loads is projected for 2050 under even the most conservative of human use and climate change scenarios (IFPRI & Veolia, 2015). By 2050, an estimated one fifth of the global population will face risks from eutrophication, and one third will be exposed to water with excessive nitrogen and phosphorous (WWAP, 2017). Countries that rely on their inland fisheries as an important food source will be particularly impacted by increasing level of organic pollution.

Salinity pollution occurs when the concentration of dissolved salts and other dissolved substances in rivers and lakes is high enough to interfere with the use of these waters. In freshwaters, salinity is commonly defined and measured as the mass of "total dissolved solids" (TDS). Important human sources of salinity stem from irrigation return flows, domestic wastewater and runoff from mines. Salinity pollution can obstruct water supply for irrigation and has wide-ranging negative impacts on aquatic ecosystems (Cañedo-Argüelles *et al*., 2013). TDS concentrations have increased in 31% of the river stretches assessed in South America, Africa and Asia (UNEP, 2016a).

Improving water quality through natural ecosystems is a key ecosystem service that can be used by nations and municipalities as they plan for the use of both grey (built infrastructure such as water treatment plants) and green infrastructure (natural infrastructure such as riparian vegetation) to provide high-quality water and reduce untreated wastewater. Wetlands and other habitats can act as important biofilters for water moving through landscapes**.** Slowing the movement of water can allow pollutants and other hazardous materials to settle out, bind to sediment and decompose before entering water supply systems. Pollutants such as agricultural nutrients, pesticides, herbicides and heavy metals from mining can be reduced by landscape planning and engineering to retain and decompose pollution through riparian buffers, wetlands, aquifers and soil health (Brauman, 2015). However, there are natural limits to the assimilative capacity of ecosystems, beyond which they are threatened and can no longer perform this purifying role. Once the concentration of pollutants in runoff reaches critical thresholds, there is a risk of abrupt and irreversible environmental change (Steffen *et al*., 2015).

Target 6.4: By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.

Global water withdrawal from dam infrastructure doubled between 1960 and 2000, with smaller increases after the 1980s in Europe and North America, and more substantial increases (>100%) for Africa, Central, West, and South Asia, Western USA, Mexico, and Central South America (Chao *et al*., 2008; Wada *et al*., 2011). Groundwater abstraction rate has at least tripled over the past 50 years and continues to increase at an annual rate of 1–2% (WWAP, 2012). There is widespread agreement that these levels of withdrawal of surface water and groundwater are unsustainable and will have ripple effects on the sustainability of irrigation for food production (Gleick, 2010; MacDonald, 2010; Vörösmarty *et al*., 2010; Wada *et al*., 2010). This trend is supported by Wada *et al*. (2014), who assessed global water use for 1960–2010 and 2011–2099, using the Blue Water Sustainability Index ((BlWSI), which incorporates both non-renewable groundwater use and non-sustainable water use that compromises environmental flow requirements. Their results reveal that ~30% of the present human water consumption is supplied from non-sustainable water resources, and this is projected to increase to ~40% by 2100.

These unsustainable water withdrawals are even more challenging in the light of water scarcity. Nearly 80% of world human population is exposed to high-level threats to water scarcity, while two thirds live under conditions of severe water scarcity at least one month per year, mostly in India and China. Half a billion people face severe water scarcity year-round (Mekonnen and Hoeskstra, 2016). Water-use efficiency improvements are therefore considered essential to address the projected 40% gap between water supply and demand, and to mitigate water scarcities by 2030 (UNEP, 2011d).

Agriculture accounts for c. 70% of total freshwater withdrawals globally and for over 90% in the majority of Least Developed Countries (FAO, 2011). Without improved efficiency measures, agricultural water consumption is expected to increase by about 20% globally by 2050 (WWAP, 2012). Given these trends, improving water-use efficiency in agriculture is a critical priority. Protecting water and using it more efficiently will be essential for sustainability of food production. Globally there is high variance in water use efficiency both within and between climatic zones (Brauman *et al*., 2013). Poor infrastructure and irrigation practices also dramatically contribute to water use inefficiencies in agricultural production. For example, leaks can create puddles and breeding grounds for disease carrying species (e.g, *Anophelese* mosquitoes, which can have health impacts relevant to targets under SDG3).

Brauman *et al*. (2013) calculated that raising crop water productivity in precipitation-limited regions to the 20th percentile of productivity would increase annual production on rainfed cropland by enough to provide food for an estimated 110 million people, and water consumption on irrigated cropland would be reduced enough to meet the annual domestic water demands of nearly 1.4 billion people. Currently, significant investments and advancements are being made in crop breeding for higher water use efficiencies (e.g., CGIAR's Seeds4Needs program), as well as shifts in crop planting patterns to track local climate (e.g., Crimmins *et al*., 2011; Kelly & Goulden, 2008; linking to SDG 2.4). Better matching crops to available water and precipitation patterns can help to reduce demand and diversion for irrigation with the co-benefit of diversifying human nutrition (e.g., SDG 2.1) and promoting local associated biodiversity if crop species are native (e.g., SDG 15.1).

Water scarcity emerges from a combination of hydrological variability, high human use, climate change and desertification, and may in part be mitigated by storage infrastructure (UNESCO, 2016). Increasingly, an environmental flow requirement is also factored into calculations of water scarcity to account for sustainability of the withdrawals (Wada *et al*., 2014). This is an important conservation and sustainability measure for nature and NCP.

Target 6.5: By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate.
Water is not confined within political borders. An estimated 148 states have international basins within their territory (WWAP, 2012), and 21 countries lie entirely within them (WWAP, 2012). In addition, about 2 billion people worldwide depend on groundwater supplies, (ISARM, 2009; Puri & Aureli, 2009), which include 263 transboundary river basins and approximately 300 transboundary aquifers (UNECE, 2015). There is a growing attention to resolving the increasing competition for water between ecosystems and socioeconomic sectors, enabling progress towards better-integrated water management and more sustainable development. However, around two thirds of the world's transboundary rivers do not currently have a cooperative management framework (Samuelson *et al*., 2015). In 2012, UNEP found that 64% of countries had developed integrated water resources management plans and 34% were in an advanced stage of implementation. However, progress appears to have slowed in countries with low and medium Human Development Index (HDI) values since 2008 (UNEP, 2012).

Target 6.6: By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.
Protecting and restoring freshwater ecosystems presents unique challenges due to their interconnected nature. For example, although there are approximately 2300 Ramsar Wetlands of International Importance, upstream unprotected areas often impact on the health of the downstream Ramsar Sites. The development of indicators measuring protection of water-related ecosystems should account for how this connectivity impacts on the health of protected water-related ecosystems. The Ramsar Convention, therefore, measures trends in the protection of water-related ecosystems, not only in terms of spatial extent, but also in terms of the quantity and quality of water in ecosystems, and the resulting ecosystem health (Dickens *et al*., 2017).

Although progress has been made in expanding protected area extent, shortfalls remain in coverage of areas of importance for freshwater biodiversity, ecological representation, connectivity, management effectiveness and equity (Juffe-Bignoli *et al*., 2016b). On average, only 44% of each freshwater Key Biodiversity Area is covered by protected area (**Figure 3.3b**; BirdLife International *et al*., 2018). Protection of source watersheds and their associated water supply also requires further attention. Approximately one third of the global population, living in 4000 of the world's largest cities, depend on source watersheds for their water supply, and this is projected to increase to two thirds of the population by 2050 (Abell *et al*., 2017). Forty per cent of these urban watersheds show high to moderate levels of land degradation. It is estimated that protection and restoration of mountain, forest and mixed-use lands in these urban watersheds could significantly reduce the sediment or nutrient potential for 81% of the cities studied.

Evidence suggests that many freshwater ecosystems are imperiled. Key threats to water-related ecosystems are changes to water source (land cover change), timing (flow regime), quantity (overextraction), and quality (pollution). Habitats representing 65% of continental discharge are classified as moderately to highly threatened (Vörösmarty *et al*., 2010). Approximately 46% of large rivers are affected by dams and their associated reservoirs (Lehner *et al*., 2011). In addition, freshwater species across a range of vertebrate and decapod groups are at greater threat of extinction than those in terrestrial ecosystems (Collen *et al*., 2014).

SDG 13: Climate action

Ongoing anthropogenic processes are altering the atmosphere and climate system, with forecasted increases in global average temperatures of around 1°C by 2050 and potentially 5ºC by 2100) (IPCC, 2015). The intensified hydrological cycle associated with these temperature increases includes altered precipitation patterns, amplifying droughts and flood events. Global sea-level rise is occurring and expected to increase by 20–40 cm by 2050 and 50–80 cm (or more) by 2100, increasing the exposure and vulnerability of human populations and settlements (Bedsworth & Hanak, 2010; Ketabchi *et al*., 2016) especially in the developing world (Thornton *et al*., 2014).

Conservation and sustainable use of nature and NCP depends to a great extent on progress to SDG 13, and at the same time could support progress to it. Progress toward attainment of SDG target 13.1 may be accelerated or undermined by policies laid out in SDG target 13.2. Climate change will increase tensions between the often conflicting goals of economic development and nature and NCP management (Bedsworth & Hanak, 2010). The achievement of several other SDGs depends, in part, on progress the achievement of SDG 13 targets.

Target 13.1: Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.
Progress toward attainment of SGD Target 13.1, focused on resilience and adaptive capacity, has been made in terms of

general awareness and acceptance on the need for action, but limited progress in terms of coherent action, despite the extensive geographical exposure to hazards. However, it is difficult to assess mobilization and response levels beyond general characterizations at the regional level, given a lack of comprehensive reporting over time through the existing frameworks. Most analyses of climate change impacts and climate adaptation and mitigation published to date have focused on issues related to ecosystems, economies, public health, and resource management, with far less attention to issues related to disaster resilience, energy security, food security, and poverty (Deng *et al*., 2017). Most of these analyses conducted have been global in scope, and do not consider local level impacts (Deng *et al*., 2017).

By contrast, the "sustainable adaptation" (SA) approach seeks to promote development while also addressing underlying drivers of vulnerability (Eriksen and O'Brien, 2007). Social and environmental sustainability criteria have been incorporated into climate-oriented development approaches identified by various names (e.g., climate compatible development, climate-proofing, climate-resilient development, climate-smart development).

To lessen the likelihood and severity of climate-driven disasters, one SA approach that has been gaining widespread use is 'ecosystem-based approaches for adaptation' (EbA) which seeks social, environmental, and economic benefits beyond the scope of technical, engineering-based approaches planned and implemented at the local level (Bourne *et al*., 2016; Doswald *et al*., 2014; Munroe *et al*., 2012). EbA adoption efforts have been underway in various locations around the world, with examples including climate change-oriented forestry practices, dryland practices relating to farming and livestock management, and floodplain/wetlands conservation and restoration (Bourne *et al*., 2016; Iacob *et al*., 2014; Kroll *et al*., 2016; Pramova *et al*., 2012).

EbA is a set of management actions to improve the adaptation of a human-natural system. One outcome is to map systematically the production and distribution of ecosystem services to better understand the underlying bases of NCP and GQL that are by extension integral to resilience and adaptive capacity (Naidoo *et al*., 2008). This requires a better understanding of adaptive practices (Sietz & van Dijk, 2015; Sietz *et al*., 2017). Further analysis is needed to establish linkages between the biophysical provision of NCP and the socially constructed values of GQL, and how those in turn connect with resilience and adaptive capacity. This perspective fits with calls for a more "holistic ecological all-hazard inter-disciplinary risk management and capacity-building model" (Buergelt & Paton, 2014: 591).

Efforts to boost resilience and adaptive capacity advocated for this target may benefit from addressing the root causes of vulnerability at the regional and societal levels, where the degree of vulnerability is a function of adaptive capacity, exposure, and sensitivity (Sietz *et al*., 2017; Kok *et al*., 2016). Analyses at different scales can provide a more differentiated discussion of opportunities for sustainable intensification at a regional scale (Sietz *et al*., 2017).

Target 13.2: Integrate climate change measures into national policies, strategies, and planning.

Major progress towards integrating climate change measures into national policies, strategies and planning was made with the adoption of the Paris Agreement, which entered into force in 2016. As of February 2018, 174 Parties have ratified, approved, accepted, or acceded to the Agreement out of 197 Parties to the Convention. Parties develop independent Nationally Determined Contributions (NDCs) to lower their emissions. These national-level climate action and emissions-reduction contributions are prepared to reflect Parties' unique circumstances, including economic and environmental differences. NDCs or action taken to achieve NDCs include "nature-based solutions" based on sustainable management and conservation of carbon-storing terrestrial (e.g., forests and peatlands) and coastal ecosystems (e.g., mangroves, salt marshes and seagrass).

As of February 2018, only six of the top 50 countries by forest area had not ratified the Paris Agreement (Lee & Sanz, 2017). Of these, Russia has the largest forest extent (522 million hectares) (Lee & Sanz, 2017). The top three countries that have not yet ratified that have the largest CO_2 emissions associated with net forest change are Tanzania, Myanmar, and Venezuela (Lee & Sanz, 2017). The ratification, approval, acceptance, or accession of the Paris Agreement by the majority of countries represents initial progress. The majority of Parties included forests, agriculture, or other ecosystems in the mitigation components of their NDCs. Parties also indicated that they will take action to enhance adaptation in these ecosystems. NDCs do not have to specify how a country intends to meet its contributions or what specific measures it will take, including with respect to ecosystem-based actions. However, NDCs can be key in motivating countries to develop terrestrial ecosystem management and conservation strategies. Similarly, coastal ecosystems – salt marshes, seagrasses, and mangroves – have been shown to be major carbon sinks or "blue carbon", with some demonstrating higher areal carbon sequestration potential than terrestrial forests (Herr & Landis, 2016; Howard *et al*., 2017). More than 150 countries have at least one major blue carbon ecosystem. As of 2016, 28 countries specifically referenced coastal wetlands in their NDCs and 59 countries included coastal ecosystems in their adaptation strategies (Herr & Landis, 2016).

Significant challenges remain for creating greater transparency with respect to how some Parties intend to achieve their NDCs. In particular, greater detail should be provided on accounting approaches for the land sectors of NDCs, including forest-related emissions and removals, harvested wood products, and the treatment of natural disturbances within NDCs (Lee and Sanz, 2017).

Target 13.3: Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning.
Climate change and its associated risks continue to be challenging to communicate to the general public. Similarly, human and institutional capacity to sustainably manage natural ecosystems for climate change mitigation and adaptation remain challenges. Progress has been made on planning and coordination, demonstration, and pilots for REDD+ readiness (Minang *et al*., 2014) and implementation. Capacity for monitoring, measurement, reporting and verification (MRV) of forests in developing countries for REDD+ as well as for NDCs is highly variable. Significant capacity-building has been carried out with respect to MRV, financing, benefit-sharing and policies, and law and institutions, although further efforts are needed (Minang *et al*., 2014).

Target 13.A: Implement the commitment undertaken by developed-country Parties to the United Nations Framework Convention on Climate Change to a goal of mobilizing jointly $100 billion annually by 2020 from all sources to address the needs of developing countries in the context of meaningful mitigation actions and transparency on implementation and fully operationalize the Green Climate Fund through its capitalization as soon as possible.
Progress has been made in financing climate change mitigation, although current capitalization falls far short of the $100 billion goal. Initial efforts to mobilize resources for the Green Climate Fund raised $10.3 billion, but further fundraising efforts may be more difficult following the United States' decision to withdraw from the Paris Agreement, increasing the burden for other donors, particularly in the European Union (Cui & Huang, 2018). These funding efforts remain critical because of analyses that show that in spite of the high costs associated with the implementation of climate mitigation plans, most developing countries would face even higher costs in case of inaction (Antimiani *et al*., 2017).

Target 13.B: Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing States, including focusing on women, youth and local and marginalized communities.
The need for capacity-building has been recognized in many climate change-related planning and management projects including those funded by the Global Environment Facility (Biagini *et al*., 2014). However, analyses of REDD+ projects and payment for ecosystem service schemes suggests that capacity-building and benefit-sharing remain key challenges (Dougill *et al*., 2012; Cadman *et al*., 2017). A focus on gender issues within climate change adaptation planning and management is relatively nascent and there is currently scant evidence as to progress in capacity-building for women, youth and marginalized communities.

SDG 14: Life below water

Achieving the targets under SDG 14 will have direct impacts on the health of marine ecosystems and their ability to provide NCP not only in relation to this goal, but also for several other SDGs. Previous assessments of anthropogenic stressors to marine ecosystems have found that nearly all of the ocean is affected by human activities (Halpern *et al*., 2008). Updated analyses indicate that 66% was experiencing greater cumulative impact in 2013 than in 2008 (Halpern *et al*., 2015a). Increases in climate change stressors, including sea surface temperature anomalies, ocean acidification, and ultraviolet radiation, drove most of the increases (Halpern *et al*., 2015a). The intensity of these anthropogenic impacts varies by location and ecosystem, but there is widespread evidence that they are having major impacts on the health of marine ecosystems (Halpern *et al*., 2012, 2015a, 2015b).

A global assessment of the health and benefits of the oceans suggest that ocean health requires significant improvement to achieve major goals including several of the SDGs (Halpern *et al*., 2012, 2017). Global scale assessments of the health of individual marine ecosystems also generally detail major declines over the last 20–50 years, with significant regional variability. For example, kelp ecosystems have experiences declines in abundance in 38% of ecoregions, increases in 27% of ecoregions, and no detectable change in 35% of ecoregions (Krumhansl *et al*., 2016). In other ecosystems, the declines are more consistent and pervasive. Mangrove ecosystems have declined in global extent by about 38% by 2010 (Thomas *et al*., 2017), with an estimated loss of 40% of mangroves over the last 30 years in Indonesia, which has the greatest extent worldwide (Murdiyarso *et al*., 2015). Recent work suggests these deforestation rates may be slowing, but mangroves are still declining at a rate of approximately 0.18% per year on average across Southeast Asia (Richards & Friess, 2016). There is considerable variability among countries in deforestation rates, with the highest losses in Myanmar, Indonesian Sumatra and Borneo, and Malaysia (Richards & Friess, 2016). Seagrass ecosystems have experienced similar declines with historical loss rates of 30% and estimates of 7% loss per year since 1990 (Waycott *et al*., 2009). Tracking global and regional trends in the status of most marine ecosystems remains challenging, particularly for ecosystems that require regular field sampling, including benthic and pelagic ecosystems, as well as coastal ecosystems like oyster reefs, dunes and salt marshes.

Two marine ecosystems – coral reefs and polar ice-associated ecosystems – have receive increased attention as bellwethers for climate change-associated changes. As outlined in section 3.2 in relation to Aichi Target 10, coral reef ecosystems have been severely impacted by repeated major bleaching episodes. In aggregate, these episodes have caused major mortality and reduced global coral health (Hughes *et al*., 2018) even in some of the most highly protected areas in the world (Hughes *et al*., 2017a). Changing sea ice extent and thickness and warmer ocean temperatures are already having major impacts in Arctic and Antarctic ecosystems (Post *et al*., 2013; Saba *et al*., 2014). In Arctic ecosystems, ecological impacts of these conditions include changing productivity and seasonality, which affects the abundance and distribution of commercial fish and iconic species such as seals, whales, and polar bears (*Ursus maritimus*) (Post *et al*., 2013).

Compromised ecosystem health limits the ability of marine ecosystems to maximize the provision of a range of NCP, including nutritional, economic, coastal protection, cultural, and climate mitigation benefits. Nutritional and economic benefits from healthy commercial and small-scale fisheries are particularly important for SDGs 1, 2, and 3, among others. These fisheries support more than 260 million livelihoods (The & Sumaila, 2013) and generate substantial revenues for many countries, including US$ 80 billion in export revenues for developing countries in 2014 (FAO, 2016). In spite of their importance, there are significant challenges to managing both commercial and small-scale fisheries. As discussed in section 3.2 in relation to Aichi Target 6, the percentage of overexploited commercial fish stocks has continued to increase since 1990, although the trend towards more overexploitation has slowed in recent years (FAO, 2016). Analyses focusing on unassessed stocks – typically those in developing countries or small-scale fisheries – suggest that they are likely to be in substantially worse condition than assessed stocks (Costello *et al*., 2012).

The benefits from better management of marine ecosystems and fisheries are substantial. For example, if unassessed fish stocks were rebuilt, 64% of them could provide increased harvests (Costello *et al*., 2012). However, challenges remain with the implementation of many management tools including marine protected areas. Although there has been an increase in the extent of marine protected areas, benefits from these are limited by inadequate staffing and financial resources (Gill *et al*., 2017) and impacts from climate change (Halpern *et al*., 2015a; Hughes *et al*., 2017a). Achieving the SDG 14 targets will depend on finding ways to ensure that nature and NCP are managed sustainably.

Target 14.1: By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution.

As human populations have grown, consumption has increased and the amount of fertilizer used for agricultural practices has increased; there has been widespread recognition that these practices have resulted in impacts on marine ecosystems (as discussed in section 3.2 in relation to Aichi Target 8). There are several types of marine pollutants, ranging from debris or "trash" to contaminants like metals, sewage and nutrient and herbicide run-off from agriculture.

Marine debris has increased in recent years and is beginning to be mapped (Cózar *et al*., 2014; Eriksen *et al*., 2014). Mortality from ingestion has been reported in some species (Baulch & Perry, 2014; Wilcox *et al*., 2015), and is a major threat to others (e.g., some seabird species, Croxall *et al*., 2012) but the extent of the problem is still being investigated. One study estimates that 192 coastal countries have generated 275 million metric tonnes of plastic waste, 4.8–12.7 million tonnes of which have entered the ocean (Jambeck *et al*., 2015). Major factors that affected how much plastic waste has entered the ocean include population size and the quality of waste management systems. Without waste management improvements, plastic waste entering the ocean could increase by an order of magnitude by 2025 (Jambeck *et al*., 2015). The impacts of plastic debris on marine plants and animals suggests that mitigation is important to the health of marine ecosystems (Rochman *et al*., 2016). Waste enters even the most remote ecosystems including the deep sea (Ramirez-Llodra, 2011). Coral reefs, in particular, seem very vulnerable to plastic debris with one study estimating that contact with plastic results in a 4–89% increase in likelihood of coral disease (Lamb *et al*., 2018).

Contaminants like metals, hydrocarbons, nutrients, herbicides and sewage have been shown to reduce species richness and abundance across marine ecosystems (Johnston & Roberts, 2009) with particular impacts on coral reefs (McKinley & Johnston, 2010). Up to 70% of studies have found negative impacts of contaminants on primary production (Johnston *et al*., 2015).

Negative impacts of land-based activites on coastal ecosystems are well documented. Nitrogen inputs from agricultural run-off and atmospheric deposition of nitrogen from fossil fuel combustion (Howarth, 2008) are major causes of coastal eutrophication and so-called dead zones (Diaz & Rosenberg, 2008; Doney, 2010) with adverse effects on coastal ecosystems like salt marshes (Deegan *et al*., 2012), coral reefs (Altieri *et al*., 2017), and temperate rocky coastlines (Strain *et al*., 2014). Recovery can be slow, with ecosystem services including fisheries and coastal protection impacted for decades (McCrackin *et al*., 2017).

Improved waste management and more sustainable agricultural practices could reduce the amount of marine pollution entering the oceans (Jambeck *et al*., 2015). Results from one analysis indicate that the perceived benefits of reducing eutrophication in European marine areas could be considerable, with the predicted annual willingness to pay per person ranging from $6 for small local changes to $235 for substantial changes covering large sea areas (Ahtiainen, & Vanhatalo, 2012).

Target 14.2: By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans.

The goal of sustainable management of marine and coastal ecosystems is to ensure that they continue to deliver the multiple benefits that people rely on (Schultz *et al*., 2015). There are many examples of successful management tools for a range of ecosystems and their associated benefits (Halpern, 2003; Hilborn & Ovando, 2014; Lotze *et al*., 2011). However, management is also more than just the specific tool or tools that are implemented. Several lines of evidence demonstrate the importance of various social, cultural, and enabling conditions that may affect the ability to sustainably manage marine resources (Bodin, 2017; Schultz *et al*., 2015). For example, there is evidence that strong sociocultural institutions can such as customary taboos and marine tenure, high levels of local engagement in management, high dependence on marine resources, and beneficial environmental conditions can result in better ecosystem condition in coral reef ecosystems (Cinner *et al*., 2016). Similarly, strong leadership, the use of individual or community quotas, social cohesion and the presence of protected areas were found to be related to the successful co-management of fisheries (Gutierrez *et al*., 2011).

However, current research suggests that the condition of many marine ecosystems including kelp forests (Krumhansl *et al*., 2016), mangroves (Valiela *et al*., 2001), seagrasses (Waycott *et al*., 2009), coral reefs (Burke *et al*., 2011; Hughes *et al*., 2017a, 2018), polar ecosystems (Constable *et al*., 2014; Post *et al*., 2013; Saba *et al*., 2014; Wassmann *et al*., 2011) and deep ocean ecosystems (Ramirez-Llodra *et al*., 2011) are continuing to decline, although with regional variability. These declines indicate that sustainable management has not yet had an impact or is limited in its ability to mitigate exogenous factors like climate change (Halpern *et al*., 2015a), particularly for vulnerable ecosystems like coral reefs (Hughes *et al*., 2017a; 2017b). The effects of climate change are overwhelming even for well-managed coral reefs like the Great Barrier Reef, which has experienced recurrent coral bleaching in 1998, 2002, and 2016, leading to mass mortality (Hughes *et al*., 2017a). Local management efforts that improve water quality and promote sustainable fisheries management can help with recovery from bleaching events, but evidence suggests that they do not play a role in mitigating the severity or extent of bleaching events (Selig *et al*., 2012; Hughes *et al*., 2017a). Therefore, managing adverse impacts from both global and local stressors will be necessary for achieving healthy and productive oceans.

Target 14.3: Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels.

During 2002–2011, approximately 27% of global carbon (CO_2) emissions were absorbed by the global oceans, causing declines in surface ocean pH, also known as ocean acidification (Doney *et al*., 2014; Le Quéré *et al*., 2013). Ocean acidification poses a key threat to many species including habitat-forming species like corals, oysters and mussels. These species are expected to have decreased survival, calcification, growth, and reproduction (Kroeker *et al*., 2010; 2013; Talmage & Gobler, 2010). The vulnerability of foundation species as well as keystone species including many echinoderms to ocean acidification will result in ecosystem-level impacts (Dupont *et al*., 2010; Kroeker *et al*., 2010). Meta-analyses also suggest that ocean acidification may catalyze changes in the structure of phytoplankton communities, with potential consequences for marine food webs (Dutkiewicz *et al*., 2015). Acidification is also projected to impact deep-sea species (Levin & Lebris, 2015). In addition, there are a range of expected neurological or behavioral impacts on several commercial and non-commercial fish species, negatively affecting their ability to find suitable settlement locations, predation behaviour, and sensory functions (Branch *et al*., 2013; Stiasny *et al*., 2016). Ocean acidification rates will vary regionally, with greater rates expected in the polar and temperate oceans (Bopp *et al*., 2013). However, impacts of acidification may still be high in tropical waters because of the vulnerability of foundation ecosystem species like those forming coral reefs (Fabricius *et al*., 2011). Because ocean acidification is a result of increased CO2, progress towards mitigating it will be inextricably tied to reducing global greenhouse gas emissions.

Target 14.4: By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics.

According to the Food and Agriculture Organization of the United Nations (FAO, 2018b), 33.1% of commercial fish stocks were estimated to be overfished and 59.9% maximally sustainably fished in 2015 **(Figure 3.8)**. The percentage of stocks fished at biologically unsustainable levels has increased since the 1970s, although the rate of

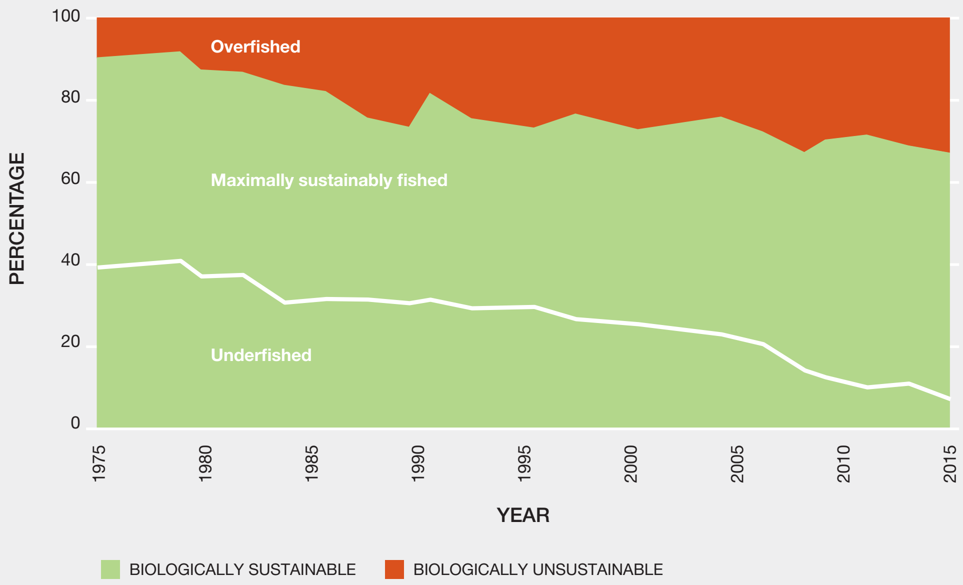


Figure 3 8 **Global trends in the state of world marine fish stocks.**

Source: FAO (2018b).

increase has slowed (FAO, 2016). Historic catch levels are difficult to estimate, but 'catch reconstructions' suggest that levels may have been higher than previously thought (Pauly & Zeller, 2016). An analysis of a larger set of stocks than those assessed by FAO suggests that 54% of stocks are below their Maximum Sustainable Yield (MSY), with 34% meeting the FAO criteria for being overfished (20% below the biomass that would support MSY) (Rosenberg *et al.*, 2017). This analysis suggests that many stocks currently classified as fully exploited could be delivering more benefits if they were more effectively managed (Rosenberg *et al.*, 2017). Small unassessed stocks are likely to be in worse condition than commerical stocks (Costello *et al.*, 2012), and would similarly benefit from rebuilding strategies.

There is significant regional variability in the status of fish stocks. For half of oceanic FAO regions, over 50% of the stocks were estimated to be below the biomass that would support maximum sustainable yield (Rosenberg *et al.*, 2017). Many of these regions were located in the northern hemisphere, which may be a result of historical exploitation patterns. Although southern stocks may appear to be in better condition, they are also generally less well-monitored, and studies suggest that stocks in data-limited regions are likely to be in poorer condition than well-monitored stocks (Costello *et al.*, 2012).

There have been considerable efforts to implement ecosystem-based management in many of the world's major fisheries. Generally, large stocks that are scientifically assessed are doing better and are generally rebuilding, rather than declining (Costello *et al.*, 2012; Hilborn & Ovando, 2014). Large, assessed stocks are likely to be outperforming small stocks or unassessed stocks because they receive more management attention, and harvesting levels can be informed by data (Hilborn & Ovando, 2014). The implementation of long-term management plans that include economic and social dimensions of fisheries have also been found to be important in achieving sustainable fisheries management (Bundy *et al.*, 2017).

Target 14.5: By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information.

As outlined in section 3.2 in relation to Aichi Target 11, significant progress has been made in increasing the percentage of coastal and marine areas that are covered by protected areas, particularly since 2000. As of September 2018, the *World Database on Protected Areas* showed that 7.44% of the marine realm was covered by protected areas (17.23% of marine areas within national jurisdiction or 200 miles from the coastline and 1.18% of areas beyond national jurisdiction) (UNEP-WCMC & IUCN, 2018). Therefore, progress towards expanding protected areas in coastal areas has been greater than in marine areas beyond national jurisdiction (the High Seas). Increases in protected area coverage have been in due in large part to the establishment of a few, very large protected areas such as those in Hawaii and the Cook Islands. Therefore, in spite of progress towards the achievement of the areal element of the target, there are indications that protected areas in the marine realm may not be based on the best available scientific information and may not be protecting ecologically representative areas or areas of importance for biodiversity (Gannon *et al*., 2017; Watson *et al*., 2016b). Research suggests the current set of marine protected areas does not capture taxonomic, phylogenetic and functional diversity well and may also not protect continued delivery of NCP in marine ecosystems (Lindegren *et al*., 2018). For example, only 44% of the area of each marine Key Biodiversity Area is covered by protected areas, on average (**Figure 3.3b**; BirdLife International *et al*., 2018).

Effective MPA design and mangement is critical to their ability to deliver ecological and social outcomes (Mascia *et al*., 2010; Edgar *et al*., 2014). Previous research has identified five key features in determining the relative success of MPAs in conserving fish species: no take regulations, enforcement, MPA age, MPA size, and degree of isolation (Edgar *et al*., 2014). Connectivity between MPAs may be particularly important for biodiversity persistence (Magris *et al*., 2018). However, there are indications that management in many marine protected areas remains relatively weak due to capacity shortfalls in staffing and funding (Gill *et al*., 2017).

Target 14.6: By 2020, prohibit certain forms of fisheries subsidies which contribute to overcapacity and overfishing, eliminate subsidies that contribute to illegal, unreported and unregulated fishing and refrain from introducing new such subsidies, recognizing that appropriate and effective special and differential treatment for developing and least developed countries should be an integral part of the World Trade Organization fisheries subsidies negotiation. Ilegal, unreported, and unregulated (IUU) fishing is estimated to impact 15% of the world's annual capture fisheries output (FAO, 2016), and developing countries with poor monitoring and enforcement are the most vulnerable to losing benefits (Agnew *et al*., 2009). The challenges of estimating the magnitude of IUU complicates efforts to understand the current status of many fisheries (Pauly & Zeller, 2016; Zeller *et al*., 2018). The 2009 Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (PSMA), which entered into force in June 2016 with binding obligations for foreign vessels entering ports, is aimed at increasing transparency and accountability (FAO, 2016). A key element of the PMSA is to implement traceability to reduce or eliminate access to markets for illegal fish products. Recent studies suggest that consolidation within the fishing industry results in 13 companies controlling 11–16% of the global catch and 19–40% of the largest and most highly valued stocks (Österblom *et al*., 2015). Implementing traceability and sustainable practices within these companies and the seafood industry may provide an opportunity to catalyze management changes at all ends of the value chain.

Current fisheries subsidies are estimated to total US$35 billion. There is no evidence that fisheries subsidies have undergone substantial changes between 2003 and 2009. Capacity-enhancing subsidies constitute 57% of subsidies, followed by fuel (22%), management (20%), and port and harbors (10%). Regionally, Asia had the highest subsidies (43% of total), followed by Europe (25%) and North America (16%). At a country-scale, Japan, United States and China had the highest levels of subsidies (Sumaila *et al*., 2016).

Target 14.7: By 2030, increase the economic benefits to small island developing States and least developed countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture and tourism. There is a lack of data on the value chains of many fisheries, making it difficult to track who benefits from fisheries and other marine resources in small island developing states and least developed countries. FAO estimates that developing economies' fisheries export share has risen from 37% to 54% of total fishery export value and 60% of the quantity by 2014 (FAO, 2016). However, many countries receive a relatively small proportional share of these benefits. Information on EU fisheries agreements suggests that the EU has subsidized these agreements at 75% of their cost, while private European businesses paid roughly 1.5% of the value of the landed fish (Le Manach *et al*., 2013). Analyses of the economic returns for small-scale fisheries in international markets suggest that fishers' earnings varied depending on species, but the relative share of value they received was negatively related to end-market value. For the highest value species, small-scale fishers received approximately 10% of the retail value (Purcell *et al*., 2017). In a study of large- and small-scale fishing sectors, researchers found that small-scale fisheries received only about 16% of the total global fisheries subsidy of $35 billion in 2009, suggesting that many small island developing states and least developed countries where small-scale fisheries are important are not benefiting from subsidies. Price transparency and changes to governance structures through fisher cooperatives could improve fisher incomes (Purcell *et al*., 2017). Awareness of these issues and implementation of proposed solutions are relatively nascent.

SDG 15: Life on land

SDG 15 aims to protect, restore and promote the sustainable use of terrestrial ecosystems including freshwater ecosystems. Nature and NCP directly underpin the achievement of the targets under SDG 15. Achievement of this goal underpins many other SDGs. Some examples of the range of NCP provided by terrestrial and freshwater ecosystems and links to other goals include: the provision of freshwater for drinking, washing, and sanitation (Goal 6), hydropower (Goal 7), and habitat for fish (Goal 14), the purification of water through prevention of erosion/sedimentation and removal of excess nutrients (Goal 6), carbon storage and sequestration for climate regulation (Goal 13), provision of food and fuel from agriculture, forestry, hunting, and gathering (Goal 12), the provision of livelihoods (Goal 8), and cultural activities such as recreation, spiritual practices and their contribution to health and well-being (Goal 3), among many others.

There is a significant degree of overlap between the Aichi Biodiversity Targets and the targets that make up SDG 15. Therefore, we summarize the key findings from section 3.2 for several of the SDG targets that overlap or are identical to particular Aichi Biodiversity Targets. SDG 15.4, which focuses on mountain ecosystems, and SDG 15.7, which focuses on taking action to end poaching and trafficking of protected species, are not the specific focus of particular Aichi Biodiversity Targets and are therefore elaborated here in more detail.

As the analysis in section 3.2 suggests, progress towards meeting the SDG15 targets for the sustainable management of terrestrial and freshwater ecosystems is generally poor.

Target 15.1: By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements.

There has been considerable progress towards achieving the target of 17% coverage of terrestrial and freshwater ecosystems by protected areas. The *World Database on Protected Areas* indicates that by September 2018, 14.87% of the world's terrestrial and freshwater areas were in protected areas (UNEP-WCMC & IUCN, 2018). However, as outlined in section 3.2 in relation to Aichi Target 11, coverage of areas of importance for biodiversity by protected areas, and ecological representation within protected areas, and connectivity between them are insufficient. For example, only 47% of each terrestrial and 44% of each freshwater Key Biodiversity Areas is covered by protected areas on average (**Figure 3.3b**; BirdLife International *et al*., 2018), while only 9.3–11.7% of protected areas are estimated to be adequately connected (Saura *et al*., 2017, 2018; **Table 3.7**). While there are few data on management effectiveness, equity, and integration with wider landscapes, it is unlikely that the global protected area network is adequate in these respects either.

Conserving and restoring terrestrial ecosystems requires limiting their loss and actively working to recover original degraded ecosystems. As outlined in section 3.2 in relation to Aichi Target 5, natural habitats from forests to wetlands continue to be lost. Losses in services provided to people from wetlands (e.g., protection from flooding, water purification) represent significant social and economic impacts (Gardner *et al*., 2015). Many terrestrial and freshwater species are threatened with extinction (**Figure 3.4a)**, while trends in the survival probability of wetland birds, mammals, and amphibians are all negative (**Figure 3.4b**; CBD SBSTTA, 2014 in Gardner *et al*., 2015) suggesting that overall these species are moving toward extinction more rapidly (see section 3.2 Aichi Target 12).

Maintaining the sustainable use of these ecosystems and the services that flow from them in the matrix outside of protected areas is critical to achieving this target. For example, conservation in managed landscapes is important for maintaining local biodiversity and nature's contributions to people (Ansell *et al*., 2016; Chaudhary *et al*., 2016; Rusch *et al*., 2016; Thompson *et al*., 2015). In the matrix in particular, strong institutions and incentives that foster behaviours that protect the health of ecosystems and the services that flow from them are critical to the achievement of this target. As outlined in section 3.2 in relation to Aichi Target 7, while some efforts to manage areas under agriculture, aquaculture and forestry sustainably (such as organic agriculture and forestry certification schemes) are increasing, biodiversity in production landscapes continues to decline, meaning that we are not making sufficient progress towards this aspect of SDG Target 15.1.

Target 15.2: By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally.

During 2000–2012, 2.3 million km^2 of forest were lost in spite of reforestation efforts (0.8 million km^2) (Hansen *et al*., 2013). As outlined in section 3.2 in relation to Aichi Target 5, although progress has been made in slowing deforestation rates (Keenan *et al*., 2015; Morales-Hidalgo *et al*., 2015), annual tree cover loss appears to be increasing (globalforestwatch.org; Hansen *et al*., 2013; Harris *et al*., 2016), suggesting that we have not yet made adequate progress on achieving sustainable forest management. For example, although Brazil has made progress in reducing deforestation, increasing forest loss in Indonesia, Malaysia, Paraguay, Bolivia, Zambia and Angola, among others, have offset those gains (Hansen *et al*., 2013). While the area under forest certification schemes has increased rapidly, much forestry remains unsustainable (see section 3.2 in relation to Aichi Target 7). Regional assessments of forest sustainability have found that unsustainable harvesting is still high in Asia, with some progress in Latin America and the Caribbean, although all regions lack data to track trends adequately in the sustainability of forest production systems (UNEP-WCMC, 2016a, 2016b, 2016c, 2016d). Efforts are underway to increase afforestation globally. For example, in May 2017, the Bonn Challenge successfully achieved pledges for the restoration of 150 million hectares of degraded and deforested lands by 2020 and 350 million ha by 2030. Achieving the Bonn Challenge could contribute an additional USD $200 billion to local and national economies and sequester enough carbon to reduce global emissions by 17% (Bonn Challenge, 2018).

Target 15.3: By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world.
Desertification may result in a loss of biological and/or economic productivity, and often involves increases in bare soil and decreases in vegetation cover (D'Odorico *et al*., 2012). Desertification affects one quarter of the world's land surface (3.6 billion ha), containing one fifth of the world's population (IFAD, 2010). Approximately 12 million ha are lost to land degradation each year, contributing to an estimated US$42 billion in income lost annually (IFAD, 2010). About 135 million people in 1995 were at risk of episodic mass starvation due to land degradation (Lean, 1995). See also section 3.4, UNCCD.

Drylands (arid, semi-arid and dry sub-humid areas) are the ecosystems most at risk of desertification. They make up approximately 41.3% of the global land area and are home to 2.1 billion people. Approximately, 44% of the worlds' cultivated systems occur in these regions and they support 50% of the world's livestock (Millennium Ecosystem Assessment, 2005). Globally, only c.8% of dryland ecosystems are protected, and 24% of this land area is degrading and in danger of desertification. Nearly 20% of the degrading land is cropland, while 20–25% comprises rangeland; about 1.5 billion people directly depend on these degrading areas (GEF-STAP, 2010).

As outlined in section 3.2 in relation to Aichi Biodiversity Target 15, there is little information on trends in restoration of degraded land, but plausible scenarios suggest little progress owing to increasing demands for commodities, water and energy.

Target 15.4: By 2030, ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development.
Mountains make up approximately 22% of the terrestrial land area, with a human population of nearly 1 billion residents (FAO, 2018a). Alpine ecosystems provide a wide range of ecosystem services including freshwater provision, erosion prevention, timber, food, medicinal plants, and opportunities for recreation. Given their wide-ranging topography and climatic diversity, isolation, disturbance regimes, and positioning along migratory corridors, mountains are home to many endemic species, significant genetic diversity, and unique cultural heritage (Spehn *et al*., 2010). Expansion of agriculture and settlements upslope, logging for timber and fuel, and replacement of alpine systems by highland pastures, climate change, and invasive species all threaten mountain ecosystems (Spehn *et al*., 2010).

Globally, nearly one in five of the world's protected areas are in mountains (Juffe-Bignoli *et al*., 2014). During 1997–2010, the proportion of mountain area covered by protected areas increased from 9% to 16% (Spehn *et al*., 2010). Protected area coverage of Key Biodiversity Areas has also grown, but on average just 48% of the extent of each Key Biodiversity Area in mountains is covered by protected areas, ranging from 18.4% in Western Asia and Northern Africa to 68% in North America and Europe (**Table 3.7**; BirdLife International *et al*., 2018), although "other effective area-based conservation measures" may effectively conserve some of the remainder (BirdLife International *et al*., 2018). In addition to protected areas, sustainable development in montane ecosystems will require the incorporation of local livelihoods and traditional ecological knowledge to develop innovative conservation and development schemes (such as payment for ecosystem services) that can be used to protect montane ecosystems and the services they provide to people. Sustainable development in mountain ecosystems must be cognizant of climate change, deforestation from landslides, societal pressures that promote emigration from small mountain towns to larger population centers, and other dynamics.

Target 15.5: Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species.
Natural habitats continue to be degraded, as noted above and in section 3.2 (in relation to Aichi Target 5). Consequently, it is unsurprising that insufficient progress has been made in efforts to halt extinction and improve the status of threatened species, with the Red List Index continuing to decline for all groups with information on trends, and indices of population abundance also showing declines in terrestrial and freshwater ecosystems (see section 3.2 on Aichi Target 12, **Table 3.7**). However, it should be noted that extinction risk trends for birds and mammals would have been worse in the absence of conservation efforts (Hoffmann *et al*., 2010, 2015; Waldron *et al*., 2017).

Target 15.6: Promote fair and equitable sharing of the benefits arising from the utilization of genetic resources and promote appropriate access to such resources, as internationally agreed.
In October 2010, CBD Parties adopted the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization. As indicated by the analysis for Aichi Target 16 (section 3.2), progress has been made in its implementation, but its goals have only

partially been met. Operationalizing the Nagoya Protocol through political will and providing financial resources has been challenging. Continued engagement and capacity-building with Indigenous Peoples and Local Communities will also be needed to ensure effective implementation.

Target 15.7: Take urgent action to end poaching and trafficking.

Poaching, illegal killing and the illegal wildlife trade has broad implications not only for species loss (Wittemyer *et al*., 2014) and spread of invasive alien species (Garcia-Diaz *et al*., 2017), but also for human health (Karesh *et al*., 2005) and socioeconomic interests (Nielsen *et al*., 2017). There are few data on the numbers of individuals of plants and animals that are poached or hunted, trapped, collected or taken from the wild illegally. As just one example, recent assessments estimated that 11–36 million individual birds are illegally killed or taken each year in the Mediterranean region (Brochet *et al*., 2016), and another 0.4–2.1 million are illegally killed or taken per year in the rest of Europe (Brochet *et al*., 2017), while illegal capture of songbirds for the cage bird trade in Asia is now driving populations extinct (Eaton *et al*., 2015). Equivalent estimates across entire taxonomic classes are not available for other groups.

To improve tracking of illegal trade, the United Nations Office on Drugs and Crime has developed a global database of wildlife seizures ('World WISE'). Initial analyses show that nearly 7,000 species have been seized (mammals, reptiles, corals, birds, fish), with no single species responsible for more than 6% of the seizure incidents (**Figure 3.9**; UNDOC, 2016).

Suspected traffickers of some 80 nationalities have been identified, with most seizures originating in Southeast Asia (Rosen & Smith, 2010). In general, illegal imports are associated with increasing exporter GDP (Symes *et al*., 2018). One analysis found higher probabilities of underreporting for avian and reptile products, with Central Africa, Central Asia, Eastern Europe and Pacific Island states showing higher underreporting than other regions, potentially suggesting complex trade networks that could allow for illegal products to be moved through legal markets (Symes *et al*., 2018). Internationally, the wildlife trade is regulated through the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which was created to limit the illegal trade and trafficking of wildlife. Implementation of the convention has been challenging due to non-compliance, an overreliance on regulation, lack of knowledge and monitoring of listed species, and ignorance of market forces (Challender *et al*., 2015a), as outlined in section 3.4.

Target 15.8: By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species.

As outlined in section 3.2 in relation to Aichi Target 9, considerable progress has been made in identifying, prioritizing and implementing eradications of invasive alien species, particularly on islands, with substantial benefits to native species. For example, over 800 invasive mammal eradications have been successfully carried out, with estimated benefits for at least 596 populations of native terrestrial species on 181 islands (Jones *et al*., 2016). There

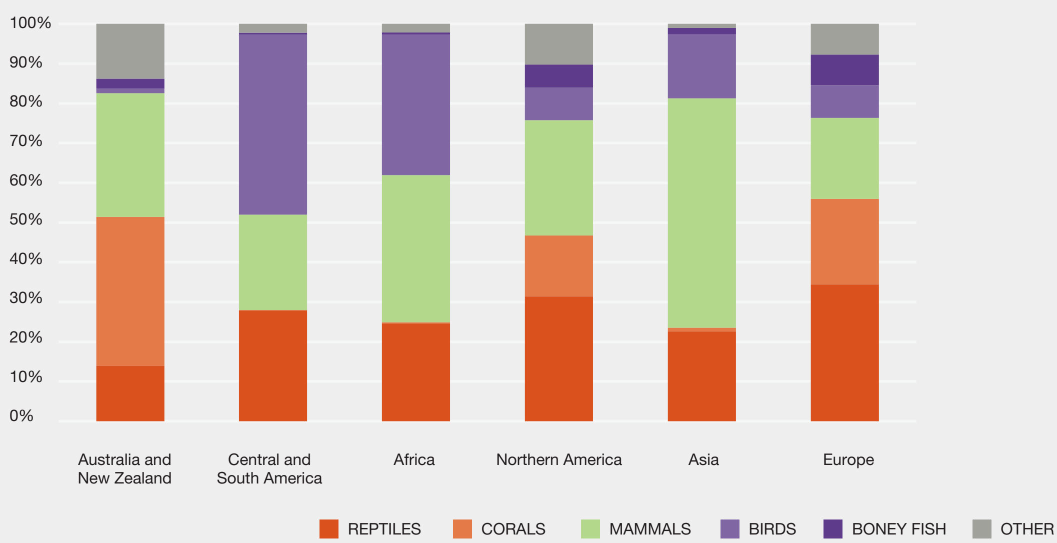


Figure 3 9 **Seizures of illegally trafficked animals, by taxonomic class and region for 1999-2015.**

Source: UNODC (2016).

are fewer data on the extent of measures to prevent the introduction and establishment of invasive alien species, but the rate of introductions is increasing (Seebens *et al*., 2017), and invasive alien species are driving more species towards extinction (see section 3.2). Globally, invasive alien species have a strong negative influence on the abundance (but apparently not species diversity) of aquatic communities, particularly macrophytes, zooplankton and fish, with invaded habitats showing increased water turbidity, and nitrogen and organic matter concentration, which are related to the capacity of invaders to transform habitats and increase eutrophication (Gallardo *et al*., 2016).

Target 15.9: By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts.

As noted in section 3.2 in relation to Aichi Target 2, some progress has been achieved in integrating biodiversity values into development and poverty reduction strategies and planning processes and in incorporating biodiversity values into national accounting and reporting systems. The global community has made significant advancements in the science of ecosystem services and in communicating the importance of biodiversity and ecosystem services in policy and planning, yet implementation of responses to address the loss of nature and NCP lags (Guerry *et al*., 2015). The System of Environmental and Economic Accounting (SEEA) has been adopted by the United Nations Statistical Commission, but integration of this framework into national accounting systems has been limited to date (Vardon et el. 2016). Examples of countries integrating ecosystem services considerations into national development planning include: China, where ecosystem service information has been incorporated into national development planning through the creation of Ecosystem Function Conservation Areas (Ouyang *et al*., 2016); Belize, where ecosystem service information has been integrated into national coastal zone planning (Arkema *et al*., 2015), and the Bahamas, where the Office of the Prime Minister has recently completed a pilot sustainable development plan for Andros Island that integrates ecosystem and biodiversity values into planning (Government of The Bahamas, 2016). These examples highlight that there is momentum to incorporate ecosystem values in national accounting (through programs like the Wealth Accounting and Valuation of Ecosystem Services Partnership) and poverty reduction strategies), but the extent to which this will be accomplished is still unclear, as are the potential impacts in policy and planning.

Target 15.A: Mobilize and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems. Target 15.b. Mobilize significant resources from all sources and at all levels to finance sustainable forest management and provide adequate incentives to developing countries to advance such management, including for conservation and reforestation.

These targets overlap considerably with Aichi Biodiversity Target 20 (see section 3.2). While financial resources for implementing the Strategic Plan for Biodiversity 2011–2020 have grown, they are still insufficient for its effective implementation. At the same time, there has been no significant increase in funding levels **(Table 3.7)**, suggesting resources are still insufficient to achieve progress toward international conservation goals (Tittensor *et al*., 2014).

3.3.2.2 Cluster 2: Nature's contribution to people (specific targets; SDGs 1, 2, 3, 11)

SDG 1: No poverty

Goal one of the SDGs calls for an end to extreme income poverty and halving of multi-dimensional poverty by 2030. The goal also aims to ensure social protection for the poor and vulnerable, to ensure equal rights to economic resources (including natural resources) and access to basic services, and to build the resilience and reduce the vulnerability of people to harm from climate-related events and other economic, social or environmental shocks and disasters.

There is a large literature examining the empirical relationship(s) between development, poverty levels (and/or human well-being) and nature (Schreckenberg *et al*., 2018). An implicit assumption is that nature and NCP can alleviate poverty, though the empirical evidence is not always available to support this, and it may be more accurate to suggest that N and NCP contribute to reducing vulnerability or preventing further declines in well-being (Balama *et al*., 2016; Suich *et al*., 2015). An increasing number of frameworks have been developed to analyse linkages between ecological and socioeconomic systems including in the context of poverty (CBD, 2010c; Fisher *et al*., 2014; Howe *et al*., 2013; Lade *et al*., 2017; Roe *et al*., 2014). These frameworks examine the links and pathways between nature and NCP and socioeconomic systems, typically examining bundles of ecosystem services (Reyers *et al*., 2013) and recognizing the multiple dimensions of poverty (i.e. not only income poverty) or well-being (Hamann *et al*., 2015). To avoid oversimplifying relationships, these frameworks typically highlight the dynamic, nonlinear and complex nature of the relationships and linkages examined, they further enhance understanding of trade-offs across disaggregated groups of beneficiaries (e.g., Daw *et al*., 2011b). In general research shows that the linkages and causality are highly context-specific, multi-scalar, subject to external factors and dynamic and need to be analyzed at the relevant scale, while looking at the appropriate elements of linked ecological and socioeconomic systems (Lade *et al*., 2017). However, knowledge gaps remain regarding causality, as well as evidence of mechanisms (Delagado & Marin, 2016; Wagner *et al*., 2015).

Empirical studies have tended to focus on the direct relationship between material needs and material contributions but focus less on the more complex relationships involving non-material and regulating NCP that underpin these relatively strong and direct links (OECD, 2013 cited in Hossain *et al*., 2017). Furthermore, factors that mediate the impacts of nature on multiple dimensions of poverty, including drivers of change, legacy effects, and contextual and external factors are also critical considerations, because of their impact on the effectiveness of management choices, and which interact with each other across multiple scales (temporally and spatially). Governance mediates the effects of interventions between nature and poverty outcomes (Swiderska *et al*., 2008); indeed, governance quality is critical to the success of policy design, implementation and subsequent outcomes. In a review of papers examining large-scale forest restoration and local livelihoods, nearly 60% of papers discussed the importance of governance to socioeconomic outcomes (Adams *et al*., 2016). This is particularly important for the analysis of high-level target-setting and reporting of achievement, as aggregated analyses may mask nuance and variation revealed by analyses conducted at scales more appropriate to the social and ecological systems being studied. Disaggregation of impacts across social groups is critical to understanding the impacts of any intervention (Daw *et al*., 2011b), though such disaggregated analyses (e.g., by ethnicity, gender, wealth categories) are infrequently presented.

Power relations also impact the ability of nature to contribute to the poor, through their effect on institutions and governance (via their mediating influence on access, use and management), with the potential to support sustainable and equitable outcomes, or produce poor outcomes, both socially and environmentally (Berbes-Blazquez *et al*., 2016). These power relations, along with local history and societal structures affect the distribution of benefits derived from the access to and utilization of NCP (Felipe-Lucia *et al*., 2015), and should therefore be explicitly assessed in order to determine whether environmental changes and resource use reinforce unequal social relations, or may be purposely used to do so (Lakerveld *et al*., 2015). In combination with power relations, the different types of values that can be held by different groups of people are also critical to outcomes, in particular through their influence on trade-offs between policy choices and desired outcomes (and these values were in turn strongly influenced by social relations, cultural norms, historical and political factors) (Dawson & Martin, 2015; Horcea-Milcu *et al*., 2016). The role of culture in determining well-being and relations between human and natural systems is also of interest (Lade *et al*., 2017; Masterson *et al*., 2016)

In assessing such high level goals as we do here, caution should be exercised given that the aggregation of data, and the use of averages can obscure the identification of winners and losers – intentionally or otherwise (see also Dawson & Martin, 2015) – and thus cement or exacerbate inequities. Thus, caution should be exercised in trying to predict the impacts of policies to achieve the SDGs; emphasis should be placed on undertaking analyses at the appropriate scale, and in incorporating consideration of local mediating and contextual factors.

Additional targets under SDG 1, not assessed here, relate to the creation of sound policy frameworks, and the mobilization of resources to implement these poverty reduction policy frameworks. The achievement of these latter targets will not necessarily directly impact on nature and NCP. However, the achievement of SDG 1 is likely to be sought through economic growth policies and through infrastructure development investments (in line with SDGs 8 and 9). Other implications include migrations of rural poor to urban areas which may result in the encroachment on agricultural land by urban areas (with knock-on effects on the achievement of SDG 2 and on management of agricultural land elsewhere) (Singh & Singh, 2016). Other impacts of the achievement of this goal are likely to be an increase in both material consumption and the generation of waste (e.g., SDG 12) and the displacement of the sites of impact on nature and NCP from the location of the consumers of goods and services (Holland *et al*., 2015; Laterra *et al*., 2016). While it is possible to design development policies to minimize and mitigate potential negative impacts on nature and NCP (Megevand, 2013; OECD, 2008; Perch, 2010; UNDP *et al*., 2009; WRI, 2005), historically this has not always occurred. Other strategies have the potential to reduce the direct utilization of nature and NCP (e.g., via job creation strategies in the services sector), though this may rather replace direct utilization with indirect utilization and/or increase consumption of certain resources. Such strategies are not always successful in their poverty alleviation objectives, as evidenced by nearly 38% of workers in developing countries living below the poverty line in 2016 (UNESC, 2017). See section 3.3.2.4.

Target 1.1: By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.90 a day.

Nature and NCP make direct contributions to the rural and urban poor, through direct consumption or the income generated by trade (e.g., food, fibre, fuel and fodder). Nature and NCP and other non-marketed goods are estimated to account for 47–89% of the 'gross domestic product of the poor' (i.e. the total source of livelihood of rural and forest-dwelling poor households), while agriculture, forestry and fisheries contribute only 6–17% of national GDP (TEEB, 2010). Studies have tended to focus on such contributions to the rural poor (e.g., Cavendish, 2000; Duchelle *et al*., 2014a; Hogarth *et al*., 2013; Schaafsma *et al*., 2014), and have considered both cultivated (Bailey

& Buck, 2016; Liu *et al*., 2010; Poppy *et al*., 2014) and non-cultivated contributions (Jagger *et al*., 2014; Shumsky *et al*., 2014), as well as some regulating contributions, such as pollination, which is critical to the continuing flow of provisioning services (Ashworth *et al*., 2009). Given large numbers of people still living in extreme poverty (especially in the rural context) for whom nature and NCP continue to provide important contributions to livelihoods, trends in environmental degradation highlighted in section 3.2 could increase the vulnerability of the poorest and undermine progress to this goal. However, high levels of uncertainty and complexity around the contribution of nature to this target, as well as unclear implications of trends in nature and NCP for this target imply we cannot current assess trends **(Figure 3.13)**. Due to the focus of this target on a poverty line of $1.90/day, changes in non-income related aspects of vulnerability and poverty could be missed.

Where opportunities for commercialization are identified as a means to increase the income that can be earned from nature and NCP, the quality of management or governance underpins any outcome. Problems have been identified in cases of newly created markets for ecosystem services, due to the potential to reinforce negative outcomes, failing to generate livelihood improvements and to achieve environmental improvement objectives, even leading to further degradation (Kronenberg & Hubacek, 2016). The equity of access to, and utilization of, nature and NCP, as well as the distribution of benefits generated (Gross-Camp *et al*., 2015; McDermott *et al*., 2013) is also of critical importance to whether the environmental and poverty goals can be simultaneously achieved.

Target 1.2: By 2030, reduce at least by half the proportion of men, women and children of all ages living in poverty in all its dimensions according to national definitions.

The multidimensional nature of poverty acknowledged in this target, is key to understanding the implications of changes in nature and NCP for poverty alleviation. Dimensions that have been included in international analyses include health, education and standard of living (both measured in the Human Development Index, HDI, and the Multidimensional Poverty Index, MPI; UNDP, 2016), the basic materials for a good life, health, good social relations, security and freedom of choice and action (used in the Millennium Ecosystem Assessment, 2005; Narayan & Petesch, 2002; Narayan *et al*., 2000a; 2000b). In a more comprehensive assessment, 15 non-income dimensions – food, health, water, sanitation, education, voice, relationships, violence, environment, time use, work, shelter, clothing and footwear, reproductive health and energy/fuel are included in the Individual Deprivation Measure (Bessell, 2015). Several country-level studies have also been conducted, and utilized a range of dimensions, include the provincial indices of deprivation in South Africa (income and material deprivation, employment, health, education, living environment; Noble *et al*., 2006) and Mexico, and the MPI calculated for more than 100 developing countries (using the standard MPI dimensions). Of these, several relate specifically to individual sustainable development goals, including – and especially – those related to health, food and nutrition security, water and sanitation and access to clean energy, which are discussed in the relevant SDGs below.

Evidence suggests that people in rural areas are more likely to be multi-dimensionally poor than people in urban areas (UNDP, 2016). Trends in nature and NCP highlighted in section 3.2 and in Cluster 1 SDGs will have mixed implications across these multiple dimensions, with positive outcomes for some (e.g., nutrition) and negative for others (e.g., water quality). We are therefore currently unable to report a nature or NCP related trend for this target **(Figure 3.13)**.

Target 1.4: By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance.

Many studies have been undertaken to determine whether richer or poorer households use NCP to a greater extent (Narain *et al*., 2008; WRI *et al*., 2008) and the gender distribution of use and the benefits derived (Pouliot & Treue, 2013). Overall, use is highly context-specific, depending on location, resource and cultural factors, among others. In some locations, external shocks may change utilization patterns, and access to resources can help households to deal such shocks, for example, utilizing forests to harvest building materials to rebuild following floods (López-Feldman, 2014; Parvathi & Nguyen, 2018). Regardless of which groups use certain resource more, there can be no doubt that continued – and secure – access to land and other resources is essential to reducing vulnerability and to prevent worsening poverty. Clear and secure land tenure has been identified as central to many policy initiatives designed to simultaneously achieve poverty reduction and environmental conservation (e.g., payments for ecosystem services, REDD+ (Duchelle *et al*., 2014b; Tacconi *et al*., 2010) and to increasing agricultural productivity (Lawry *et al*., 2017).

Clarity and security of land and resource tenure is particularly important in the face of policies supporting the industrialization of agriculture, which can create conflict, such as that experienced with the expansion of oil palm in Indonesia (Feintrenie *et al*., 2010; Rist *et al*., 2010), and to prevent the damaging effects of 'land-grabs' (on large and small scales) which can severely compromise dimensions of poverty including (local) food security and health and can increase the inequity of land distribution (Borras *et al*., 2011; Feldman & Geisler, 2012; Visser *et al*., 2012). Inequity in land distribution has been identified as being at the root of many agrarian and environmental problems, for example across Southern Africa, and post-independence reforms have largely failed to address these, and in some cases, have reinforced threats to social, economic and environmental sustainability and security (Clover & Eriksen, 2009). While progress has been made with respect to expanding Indigenous Peoples' rights over recent decades, constraints remain on their ability to exercise these rights (RRI, 2012), and much customarily security land remain unrecognized legally (RRI, 2015). From a small set of studies, our assessment finds poor progress to this target as it applies to equal rights to nature and NCP **(Figure 3.13)**.

Land reform can threaten access to land and resources (Fay, 2009; Jagger *et al*., 2014; White & White, 2012), or can work to improve the sustainability of management practices (Ali *et al*., 2014). Though much research has focused on issues of land tenure to date, issues of water security and entitlements and secure access to other resources is likely to increase in importance (Woodhouse, 2012), particularly in regions impacted most strongly by climate change.

Target 1.5: By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters.

Global disaster risk is highly concentrated in low- and lower-middle-income countries, with a disproportionate impact being borne by small island developing states (Hall *et al*., 2008; United Nations, 2003). The management of disaster risks has reportedly failed to deal with the underlying drivers of increased global risk – climate change, uncontrolled urbanization and the creation of assets in hazardous areas (Keating *et al*., 2017). In particular for the rural poor, ensuring security of access to necessary land and resources will contribute to the maintenance of livelihoods, and potentially to reducing vulnerability and building resilience, for example from the utilization of available nature and NCP to speed the recovery from shocks or disasters (Balama *et al*., 2016; López-Feldman *et al*., 2014).

Research on the role of nature and NCP in mitigating or reducing vulnerability to disasters is growing (Nel *et al*., 2014). At an aggregate level, investment in the sustainable use of nature and NCP tends to generate significant benefits and avoids having to replace nature and NCP with physical infrastructure to produce the same protection function (IUCN, 2003; Russi *et al*., 2013). Trends in coastal and marine ecosystems (section 3.2 and Cluster 1) relevant to reducing vulnerability to extreme events suggests negative trends hampering progress to this target **(Table 3.8)**. However, studies in the Global South on the role and condition of ecosystems in reducing vulnerability is a key gap (Liquete *et al*., 2013).

SDG 2. Zero hunger

Goal 2 of the SDGs, which calls for the elimination of malnutrition and the promotion of sustainable and productive agricultural systems, has significant direct reliance on nature and NCP (Wood *et al*., 2018). Food production (and by extension nutrition) is an emergent outcome of a multitude of supporting, material, and regulating contributions from nature. A typical crop depends on nutrient cycling by soil microbiota to maintain soil fertility and water holding capacity to keep crops hydrated, genetic diversity to withstand pest and diseases, as well as associated wild biodiversity to carry out basic functions (e.g., pollination, N_2 fixation).

Agriculture has also been identified as the major cause of land use change, land degradation and desertification, together leading to declines in nature and NCP (Millennium Ecosystem Assessment, 2005). As pressure rises on the food system to feed a growing, and increasingly wealthy population, there has been a global shift towards more intensive forms of agriculture. As a result, this goal is equally applicable in developing and developed countries alike, which both must improve agricultural performance while addressing issues of land degradation and malnutrition. Agriculture, and therefore SDG 2, is a critical nexus for the interaction of nature, NCP and GQL.

Over one third of our global croplands are now degraded (Millennium Ecosystem Assessment, 2005) and 12 million new hectares are lost from production each year (UNCCD, 2016), primarily in Asia and Africa (Gibbs & Salmon, 2015). Sustainable production is therefore essential and must also include equitable access to resources (i.e. financial, genetic, technological) and benefit-sharing for all actors along the value chain. Ensuring healthy diets and a healthy planet will require rebalancing both production and consumption.

How we set out to achieve targets under SDG 2 will have enormous consequences for the persistence of nature and its contributions to people (Figure S3.1). There is a high potential for trade-offs between targets 2.1–2.3 (i.e. increasing food production and reducing malnutrition) and targets 2.4 and 2.5 (improving sustainability and biodiversity within our farming systems). A continued and focused reliance on land clearing, intensive use of agrochemicals and homogenization of crop diversity to maximize productivity will continue to degrade the underlying biodiversity and regulating services upon which agriculture depends, as well as failing to deliver nutritious food. There are numerous potential pathways to achieving SDG 2 that could have strongly negative impacts on nature and NCP. Biodiversity of the soils, crops and management practices offer huge potential to address SDG 2 (see section S3.5).

Target 2.1: By 2030 end hunger and ensure access by all people, in particular the poor and people in vulnerable situations including infants, to safe, nutritious and sufficient food all year round.
Globally, total food production has been increasing at an average of 2.2% per year since the 1960s, with developing countries contributing significantly to this growth at 3.7% per year (FAO, 2002). Despite enormous gains in food production over the past half-century, 815 million people remain hungry (FAO *et al.*, 2017). Chronic hunger exists primarily in poorer countries, such as those in sub-Saharan Africa, Central Asia and the Indian subcontinent (FAO *et al.*, 2017). Chronic and acute hunger can be due to several different and compounding causes, including low yields and crop failure, but is increasingly driven by distributional issues and poor access to financial markets, as well as the breakdown of social safety nets and political strife (Sen, 1981). In many parts of the world, when food reserves or access to food is low, wild foods often provide important nutritional safety nets (Bharucha & Pretty, 2010; Penafiel *et al.*, 2011; Schulp *et al.*, 2014), particularly of rural, poor and disadvantaged groups (Kaschula, 2008). Wild foods are inexpensive and nutritionally important sources of energy, micronutrients and dietary diversity (Arnold *et al.*, 2011; Penafiel *et al.*, 2011). Although largely undocumented, wild foods represent important food intake globally (Scoones *et al.*, 1992) and reliance on wild foods has been found to be most important for meeting food security needs in areas of high biodiversity (Penafiel *et al.*, 2011). Wild species are often incorporated into home gardens and help to provide an important flow of food year-round (Freedman, 2015). For example, the Naxi people of China sustain their food supply during droughts by having a wide range of edible plants (38 cultivated, 103 wild), strong landrace crop diversity, and by eating all parts of plants (Zhang *et al.*, 2015). In addition to harvesting wild plants, it is estimated that 150,000 people in forest ecosystems of the Neotropics and 4.9 million people in the Afrotropics consume ~6 million tons of wild mammal meat every year, an important source of protein (Swamy & Pinedo-Vasquez, 2014). Insects are another important wild source for protein, with over 1700 known species consumed by traditional cultures, most from the Lepidoptera family, i.e. butterfly and moth larva (Ramos-Elorduy, 2009). However, it's likely that demand for these products will grow as populations in rural areas are set to double in size in places such as Africa and as harvesting techniques become more efficient.

Although data on bushmeat catch is patchy, current levels of harvesting are thought to be unsustainable and are likely to lead to species population crashes (Wilkie *et al.*, 2011). According to the IUCN Red List, over 1680 terrestrial animal from comprehensively assessed groups (19%) are threatened by overexploitation, 1118 freshwater and marine animals (13%) by fishing and a further 557 plants (6%) from gathering (Maxwell *et al.*, 2016). In some cases, demand for traditional and wild foods comes from wealthy and more urbanized households, rather than local communities (Brashares *et al.*, 2011). This demand can create a commodity market for wild species, increasing harvesting pressure and uncoupling the link to local diets. Policies that enforce protected areas but allow regulated access by local communities can help to preserve the flow of wild foods into diets of vulnerable communities and help achieve target 2.1. In order to do this, better and uniform metrics based on specific biological indicators are needed to evaluate the sustainability of wildlife harvests in hotspots of bushmeat consumption (Weinbaum *et al.*, 2013). To ensure that wild species continue to provide critical food sources, and that people have access to these resources, it is essential that species' habitats are protected, and harvesting is regulated to sustainable levels. Since 1990, there has been a global increase of 75% in conservation areas, which has helped to secure habitat for some populations. However, the biggest threats to wildlife remain overexploitation (46% of threatened and near threatened species) and encroaching agriculture (IUCN, 2012; Juffe-Bignoli *et al.*, 2014; Maxwell *et al.*, 2016; Swamy & Pinedo-Vasquez, 2014).

Beyond chronic hunger, this target highlights nutritious food as key to this SDG. To achieve a basic minimum level of health, people must consume both sufficient calories and sufficient macro and micronutrients. Two billion people experience micronutrient deficiencies (International Food Policy Research Institute, 2015; Rowland *et al*., 2015). A leading cause of micronutrient deficiency is a lack of sufficient diversity in the foods consumed. The widespread adoption of high yielding crops and western diets, supported by an increasingly homogenized global farming system (Khoury *et al*., 2014) has provided cheap calories to stave off hunger, but has significantly narrowed diets, replacing traditional and high micronutrient crops (e.g., Raschke *et al*., 2008) – a trend which has limited progress to aspects of this target **(Figure 3.13)**. Of the 7000 edible crops cultivated in human history, today just 12 crops and 5 animal species provide 75% of the world's food (FAO, 2015c). This has eroded the biological diversity, at both the genetic and species levels, on which our farming practices depend (Chappell & LaValle 2011). Compounding this problem, these high-yielding crops (rice, wheat, maize) tend to have lower micronutrient content than the traditional cereals they displace in local diets, e.g., millets, sorghum, barley, oats, rye (DeFries *et al*., 2015). This may be in part a result of the overuse of mineral fertilizers that can render soils devoid of micro-organisms important for making micronutrients bioavailable to plants, e.g., zinc (Cardoso & Kuyper, 2006). This has further links to the dual challenge of both high rates of chronic under-nutrition and rising adult obesity. Over 600 million people are obese, mostly in Europe, North America and Oceania, with many developing countries exhibiting this double burden of malnutrition (FAO *et al*., 2017).

There is strong scientific evidence, at the individual (Steyn *et al*., 2006) and national level (Remans *et al*., 2014), that increasing dietary diversity and food supply diversity are associated with positive health outcomes on acute and chronic childhood malnutrition, particularly for low income countries. In addition to agriculture, fish can provide important sources of protein and micronutrients to vulnerable populations (Kawarazuka & Bene, 2010). In 2015, fish accounted for 17 per cent of animal protein and provided 3.2 billion people with nearly 20 per cent of their average per capita intake of animal protein (FAO, 2018b).

Target 2.3: By 2030, double the agricultural productivity and the incomes of small-scale food producers, particularly women, Indigenous Peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.

Most farmers globally are smallholder farmers with less than 2 hectares of land, dominating agriculture across Africa and Asia, while moderate and large-scale farming dominates across much of Europe, North America, Australia and parts of South America (Fritz *et al*., 2015). Small-scale producers play a critical role in agricultural, aquacultural and capture fisheries productivity (FAO, 2016). It is estimated that approximately 500 million family farmers are responsible for producing 50–80% of our food (FAO, 2014a; Graeub et. al 2016). Meanwhile, approximately 56.6 million people were employed in capture fisheries and aquaculture in 2014 (FAO, 2016) of which small-scale fisheries constituted 90% of people employed in capture fisheries (FAO, 2016) and approximately half of the fisheries sector workforce is estimated to be women. Today, family farms still account for 98% of all farms, and are estimated to manage 53% of agricultural land (Graeub *et al*., 2016). As human populations are set to rise to 9 billion, increasing yield on existing croplands, especially smallholder farms where large yield gaps persist (Fischer *et al*., 2002), will be an essential component of achieving this target (FAO, 2009).

Increasing smallholder farmer access to improved crop varieties, high quality seed and inputs will be three important elements for achieving this target (see Supplementary Materials for review). Access to water is another significant limitation to increasing crop production. Many low-yielding regions experience water-stress due to low and variable rainfall as well as poor soil water retention (Brauman *et al*., 2013). In sub-Saharan Africa, 95% of agriculture depends on moisture from rain held in the soil or 'green moisture' (Rockstrom & Falkenmark, 2015). However, across much of the continent, most rain evaporates from the air and soil before creating run-off, meaning little recharge of lakes and rivers. This makes traditional irrigation infeasible as lakes and reservoirs quickly empty (Rockstrom & Falkenmark, 2015). Other regions in which irrigation is not viable include highly populated places such as northern China and central India where smallholder farming dominates. By 2025, it is expected that as much as 60% of the global population may suffer water scarcity and rely on non-conventional water resources to meet their water needs (Qadir *et al*., 2007) Smallholder, farmers will need to manage their fields and landscape to increase 'green water' storage in soils and the water table (Wani *et al*., 2009). Methods to improve 'green water' retention aim to increase soil organic matter, improve soil structure and reduce evapotranspiration and include mulching, minimum tillage and use of bunds among other land management techniques (Palm *et al*., 2014; see Supplementary Material S 3.5).

Assessments of global climate change which shows that 'blue' and 'green' water availability may be so severely affected in parts of Asia and Africa that these regions may no longer be able to sustain certain diets (Gerten, 2013). Taken together these trends in crop varieties, seeds, and inputs from NCP available to small-scale farmers, as well as trends in access and tenure from SDG 1, have limited progress to this target.

Tracking contributions and productivity from small-scale fisheries and aquaculture is a major ongoing research and management challenge. Nonetheless, it is recognized that the management of small-scale capture fisheries needs to improve not only for food security and nutrition, but also to ensure the equitable distribution of benefits and socioeconomic conditions of small-scale fishing communities. These goals are reflected in the Voluntary Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (SSF Guidelines), which were endorsed in 2014. The SSF Guidelines are intended to improve small-scale fisheries governance and food security. The small-scale aquaculture production sector is constrained by various factors, including access to financing, a lack of technical innovation, an absence of feed formulation and processing knowledge, and insufficient training. Public–private partnerships may provide an avenue to provide more resources and share knowledge to increase productivity (FAO, 2016).

Target 2.4: By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.

Much progress in reducing hunger has been achieved through the widespread use of high yielding crop varieties (including some genetically modified organisms), increased access to fertilizers (via industrialized N_2-fixation, via the Haber-Bosch process) and expanded irrigation developed during the Green Revolution. There is also significant evidence this intensification has been accompanied by deteriorating agroecosystem health from the erosion of topsoil, loss of soil structure, eutrophication of waterways and decline in farmland and soil biodiversity (Millennium Ecosystem Assessment, 2005). In Africa, low inherent soil fertility (Aihou *et al*., 1998), insufficient fertilizers use (Druilhe & Barreiro-Hurlé, 2012) and poor soil management practices are primarily to blame for land degradation. There is clear evidence that conventional agricultural intensification, along with overgrazing of livestock, has widely contributed to loss of critical NCP and function through erosion of topsoil and loss of soil structure, which has led to widespread land degradation (Millennium Ecosystem Assessment, 2005). Today over one third of croplands (1–6 GHa) have been degraded, impairing their ability to sustain high food production (Millennium Ecosystem Assessment, 2005; Pimental & Burgess, 2013) resulting in an assessment of negative trends preventing progress to this target **(Figure 3.13)**.

Substantial trade-offs with target 2.3 to double productivity are possible if previous approaches to productivity are relied upon. Conventional approaches rely on increasing external inputs (i.e. mineral fertilizers, pesticides, irrigation) to supplement or substitute ecosystem processes such as nutrient cycling, water retention and pest control in fields to boost yields (Bommarco *et al*., 2013). Widespread and continued adoption of input-intensive forms of agriculture are dramatically altering nitrogen, phosphorus and potassium cycles as well as sediment and erosion processes (Steffen *et al*., 2015). Excess fertilizers washed into water systems can cause eutrophication and algal blooms, impacting downstream freshwater and coastal fisheries.

Between 1995 and 2011, the number of known eutrophication zones rose from 195 to over 515 worldwide (Rabotaygov *et al*., 2014). Today the total global number of reported eutrophication points experiencing large algal blooms is >760 and increasing annually (WRI dataset; Diaz, 2013). The impacts of algal blooms and the dead zones the create (i.e. areas of low oxygen or hypoxia) may be particularly important for the 10–12% of the global population who depend on coastal fisheries and aquaculture for their livelihoods, 85% of whom are small-artisanal fisher folk (FAO, 2014a). An increasing number of blooms are toxic, releasing harmful toxins that can poison aquatic species and the people consuming them, particularly shellfish (Mulvenna *et al*., 2012). These are important food sources for which provide 15–20% of protein in many coastal communities (FAO, 2014a). Over the past 50 years, nitrogen-use-efficiency has improved dramatically in some parts of the world, actually reducing inputs while maintaining or increasing yields (e.g., France, Netherlands, Greece), while other countries have continued to increase fertilizer application with diminishing returns (Lassaletta *et al*., 2014). However, major disparities worldwide exist in the application (West *et al*., 2014) and efficiency of fertilizer use for key crops (Lassaletta *et al*., 2014). It is also important to acknowledge that input-scarce farming practices can be almost as damaging as input-intensive ones. Insufficient application of nutrients, excessive tilling, overstocking of animals and low crop diversity can also lead to degradation of soils and high erosion rates, impairing food production and damaging ecosystems (Lassaletta *et al*., 2014; Liu *et al*., 2010; Rudel *et al*., 2016; Vitousek *et al*., 2009). Indiscriminate use of pesticides also contributes to problems of water quality, negative impacts on farmland biodiversity and ecological functioning (Chagnon *et al*., 2015; Simon-Delso *et al*., 2015). In particular, insecticides can negatively affect decomposition, nutrient cycling and soil respiration, in large part through their negative impact on beneficial invertebrate populations that carry out these processes (Chagnon *et al*., 2015).

Increasing intensification of agriculture in terms of both agrochemical use and landscape simplification (fewer crop types, rotations and remnant habitats) has negatively impacted farmland species critical for food production. Seventy-five per cent of major crops require some degree of pollination (Klein *et al*., 2007). Loss of adequate habitat within the agricultural matrix (e.g., grassland and forest patches, hedgerows etc.) high use of agro-chemicals and the large-scale transport of hives over great distances is thought to contribute to the widespread decline of pollinators (Simone-Finstrom *et al*., 2016). Over 40% of pollinator species are threatened (IPBES, 2016), which may lead to pollinator-limited yield declines (Basu *et al*., 2011). These crops also tend to be high-value fruits and vegetables and primary sources for key micronutrients such as vitamin A, iron and folate (Eilers *et al*., 2011), affecting efforts to achieving SDG 2.1 and 2.2 on healthy diets and malnutrition. Preservation of natural vegetation within agricultural landscapes for nesting and feeding habitat (Kremen *et al*., 2004), along with reduced use of harmful agro-chemical such as neonicotinoids can help to maintain pollinator communities in landscapes and pest control services. These findings highlight negative trends in features relevant to achieving this target **(Figure 3.13)**.

In contrast to conventional intensification, ‘agroecological’ intensification is a means “by which farmers simultaneously increase yields and reduce negative environmental impacts through the use of biodiversity-based approaches and the production and mobilization of ecosystem services” (Atwood *et al*., 2017). These farming approaches, are based on the integration of ecological principles and stimulation of biodiversity interactions within fields and farms to increase productivity, reduce external inputs, and build long-term fertility for healthy ecosystems (IPBES, 2016; see Supplementary Material for review).

One of the greatest threats to agriculture is climate change. Climate change projections indicate that in every decade until 2050, food production will decline on average by 1% (Porter *et al*., 2014), but in Africa and Asia major crop yields will face an estimated average decline of at least 8% by 2050 (Knox *et al*., 2012; Schlenker & Lobell, 2010). Our farm systems are vulnerable to both rising temperatures as well as weather extremes (drought, floods etc.). Ironically, agriculture is also one of the largest emitters of greenhouse gases (GHG), accounting for 24% of carbon dioxide (CO2) emissions globally (IPCC, 2014). This is a result of multiple factors including loss of carbon following the destruction of native habitat (Fearnside, 2000), massive methane (CH4) emission from rice paddies – the second most widely planted stable crop –(van Groening *et al*., 2013) and nitrous oxide (N_2O) emissions from the application of fertilizers (Gerber *et al*., 2016). In addition, significant emissions of CO_2 are emitted from the fossil fuel inputs needed to make agrochemicals and operate machinery (Verma, 2015). Judicial use of inputs, paired with improved agro-ecological management of agricultural systems can help to improve the energy-intensity of farming practices, sequester carbon and build resilience (see Supplementary Materials).

Target 2.5: By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, as internationally agreed.

Agrobiodiversity encompassed in agricultural systems from genes to cultivar varieties and crop species, up to landscape composition, is a central element of our cultural heritage (Pautasso *et al*., 2013) and an important resource for sustainable development. The genetic diversity of both wild and cultivated species provides the basic material for crop and livestock improvement, resilience to stress and adaptation to changing conditions. The use of crop diversity in-field can improve soil function, pest control, pollination (Hajjar *et al*., 2008), yield stability (Di Falco & Chavas, 2009), resulting in improved income stability (Abson *et al*., 2013). Under an unpredictable climate, a diversity of genotypes or crops and/or livestock offers basic insurance as some varieties perform better under hot or dry conditions than others. Genetic diversity also offers the potential to develop new varieties or cultivars with beneficial traits such as resistance to emerging diseases, environmental tolerances or longevity. Wild relatives of crops that have not been domesticated provide an important genetic resource pool as they have continued to evolve under ambient environmental conditions and selection pressures, with which cultivated species can be back-crossed to acquire desirable characteristics (Dempewolf *et al*., 2014). Crop wild relatives have been and are increasingly being used in breeding programs to fight diseases and develop land races to cope with environmental stressors (Dempewolf *et al*., 2014; FAO, 2015c).

There are four types of plant genetic diversity which are important to differing degrees for breeding: wild relatives, ecotypes, landraces and cultivars (Boller & Vetelainen, 2010). Traditionally, seed exchange between farmers was central to the maintenance of agrobiodiversity (Pautasso *et al*., 2013). Modern investments and improvements in specific cultivars have led to their widespread adoption and uniformity in composition across farmlands and even between countries (Khoury *et al*., 2014). Of the 7000 crops cultivated in human history (Khoshbakht and Hammer, 2008), only 12 crops —and even fewer cultivars of those species—contribute significantly to food production and consumption today (Khoury *et al*., 2014). Such trends signal limited or mixed progress to this target **(Figure 3.13)**. Low species and genetic diversity can leave crops vulnerable to biotic and abiotic stressors (Hajjar *et al*., 2008; Zhu *et al*., 2000).

While, the genomes of the most important staple crops (e.g., rice, wheat, maize and potato) have been the subject of extensive research, conservation and development by both non-profit (e.g., International Rice Research Institute, International Maize and Wheat Improvement Center, and the International Potato Center) and agribusinesses (e.g., Syngenta, Monsanto) for decades, significantly fewer resources have gone into identifying, developing and securing the genetic diversity found in farmers' fields (FAO, 2015c). Individual country and species case studies suggest continued loss of crop genetic diversity through the widespread replacement of traditional varieties with modern high-yielding cultivars and due to land clearing, overgrazing and changing agricultural practices (FAO, 2015c). While moderate success has been made to increase the number and representation in genebanks over the past two decades, many accessions remain at risk of technical failure (FAO, 2015c). For this reason, traditional farmers who plant, maintain and exchange diverse crops, trees and wild species will remain increasingly important partners in efforts to conserve genetic resources and to identify high performing cultivars in the face of climate change and other stressors (Pautasso *et al*., 2013; Sthapit *et al*., 2014). There are substantial numbers of under-utilized and promising new species that are known to local farmers or cultivated on small scales but could benefit substantially from research investments for their promotion. The program PROTA in Africa identified 15 new cereals and 90 vegetable plants that are ideal candidates for promotion as well as protection (Lemmens & Siemonsma, 2008). Support for these efforts through agreements such as the International Treaty on Plant Genetic Resources, and the

Nagoya Protocol are critical for the conservation, exchange and sustainable use of the world's plant genetic resources in the public domain, and ensuring equitable access and benefit-sharing for all farmers.

Widespread homogenization of foods systems and genetic erosion of crop and livestock species can present a serious threat to food system sustainability (Aguilar *et al*., 2015). Much of this comes from the replacement of local and traditional land races and breeds with modern high-yielding cultivars (Biscarini *et al*., 2015), indiscriminate cross-breeding practices that leads to loss of unique species, and declining demand for animal labour with mechanization (Quaresma *et al*., 2013). Some 38 species and 8,774 separate breeds of domesticated birds and mammals are used in agriculture and food production (FAO, 2015c). However, 17% of these animal breeds are currently at risk of extinction, while the risk status of many others (58%) is simply unknown (FAO, 2015c). From 2000 to 2014, nearly 100 livestock breeds are thought to have gone extinct (FAO, 2015c). For livestock our assessment therefore shows negative trends for the target **(Figure 3.13)**. North America, Europe and the Caucasus have the greatest proportion and absolute number of breeds at risk. New efforts by groups such as the EU Globaldiv project to document goat genetic diversity across regions and continents (Ajmone-Marsan *et al*., 2014) and large genomic databases, such as the Domestic Animal Genetic Resources Information System (DAGRIS) are needed to provide systematic information on the diversity, distribution and classification of livestock, in order to properly manage and maintain these genetic resources (Dessie *et al*., 2012).

Crop wild relatives (CWR) also supply an important flow of genetic resources to support agriculture, however they are threatened by clearing and degradation of native habitats (McGowan *et al*., 2018). CWR are poorly represented with many having few or no accessions in gene banks, and over 95% insufficiently represented across their full geographic and ecological range (Castaneda-Alvazez *et al*., 2016).Wild species pollinated by insects are particularly vulnerable to loss of outcrossing and genetic erosion associated with landscape modification (Eckert *et al*., 2010) and fragmentation (Vranckx *et al*., 2012). In addition, climate change may also pose growing threat to CWR populations (Phillips *et al*., 2017). In the global protected areas network, areas of high CWR are underrepresented. Traditionally, the highest diversity of CWR occurs near the centres of origin of crop domestication (Hummer & Hancock, 2015; Vavilov, 1926), and thus incorporating CWR into *in situ* and *ex situ* conservation plans in these regions will be important for preserving wild genetic resources (FAO, 2015c). Recently, the IUCN 'Plants for People' project has set out to assess the status of 1500 priority CWR. In 2017, 26 species of wild wheat, 25 species of wild rice and 44 species of wild yam, and for the first time three species of wild rice, two species of wild wheat and 17 wild yam species have been listed as threatened on the Red List (IUCN, 2017). As more species are assessed, the IUCN Red List will become an increasingly important tool for measuring progress towards this target **(Figure 3.13)**.

SDG 3: Good health and well-being

Goal 3 of the SDGs calls for the reduction of – and end to – premature and preventable deaths associated with maternal and infant mortality, diseases (including non-communicable diseases), and deaths and illnesses from hazardous chemicals and pollution. Human health is intimately linked to nature and NCP through food, water, medicines, as well as through multiple other pathways linking nature to human well-being. For a subset of the targets listed under SDG 3 there are clear linkages between health and nature and NCP. However, there are also several more complex relationships between nature and NCP that can include positive and negative impacts on health (Oosterbroek *et al*., 2016). The links between nature and NCP to achieving the targets under SDG 3 follows several pathways which we outline below including direct impacts and ecosystem-mediated impacts.

Direct impacts of Nature and NCP on human health

Nature and NCP can have a direct impact on human health by providing nutrition (macro- and micronutrients) and as a source of traditional medicine or novel compounds for use in medicine. Large segments of the world's population depend on the consumption of wildlife for the provision of protein and micronutrients. Biodiversity declines directly threaten human nutrition and health through reduced food availability (Myers *et al*., 2013; SDG 2). It is estimated that between 1.39 and 2.9 billion people gain around 20% of their annual protein from fish (FAO, 2014a; Golden *et al*., 2016). These numbers reflect the importance of fish in the diet for vitamins and micronutrients that are essential for healthy functioning of the human body (Black *et al*., 2008; McLean *et al*., 2008). For example, deficiencies of the micronutrients found in fish (i.e. iron, zinc, vitamins A and B12, fatty acids) lead to increased risk of perinatal and maternal mortality, growth retardation, child mortality, reduced work productivity, cognitive deficits, and reduced immune function, with very large associated global burdens of disease (Black *et al*., 2008). Micronutrient deficiencies can also be ameliorated by consumption of bushmeat, ideally from sustainable sources (Rowland *et al*., 2017). A study of preadolescent children in rural Madagascar showed that consuming more wildlife was associated with significantly higher hemoglobin concentrations. Modelling suggested that loss of access to wildlife would cause a 29% increase in the numbers of children suffering from anaemia, with a much greater increase in poorer households (Golden *et al*., 2011).

Traditional herbal medicines have been defined as: "naturally occurring, plant-derived substances with minimal or no industrial processing that have been used to treat illness within local or regional healing practices" (Tilburt & Kapcuck, 2008). A few traditional medicines are now traded globally, but for many countries particularly in Africa, Asia and Latin America, locally-collected traditional medicines are a major resource for meeting primary health care needs (Dudley & Stolton, 2010). An estimated 60,000 species are used for their medicinal, nutritional and aromatic properties worldwide (UN Comtrade, 2013 analyzed in CBD, 2015) and at least 60% of medicinal plants are gathered from the wild, with some countries like India and China reportedly harvesting much higher proportion, at around 80–90% (Alves & Rosa, 2007; Muriuki, 2006). Many of these species are known to be declining in abundance due to overharvesting and habitat loss. For example, approximately 15,000 species of global medicinal plants are now classified as endangered (Schippmann *et al*., 2006). Among amphibians, around 47 species were reported to be used in traditional medicines, with a third of species belong to the family Bufonidae. Despite the number of species identified as used for traditional medicine the efficacy of most traditional medicines is not well understood, nor are the links between loss of plants and animals used in traditional cures and their concomitant impacts on human health and well-being. This is largely due to the experiential nature of most forms of traditional medicine and because they are passed on orally and so not easily harmonized with mainstream health systems or integrated in public health care (CBD, 2015).

In the last 30 years more than 2,500 different chemical compounds have been identified from marine plants and animals (Tibbetts, 2004) and between 1981 and 2010 more than 677 of the drugs approved by the US Food and Drug Administration originated in nature (Newman & Cragg, 2012). The untapped potential of the natural environment to provide novel compounds for drug development is unknown, therefore it is hard to say with certainty what impact biodiversity decline will have on the discovery of new compounds for medicinal use. There are an estimated 391,000 species of vascular plants currently known to science (RGB Kew, 2016) and of these only a small sample have been studied for their potential role in pharmacology (CBD, 2015). Of known plant species 21% are estimated as being currently threatened with extinction according to IUCN Red List (RGB Kew, 2016), while the equivalent figure for animals is 19–34% (best estimate = 22%, based on analysis of data in IUCN, 2017; see section 3.2, **Figure 3.4a**).

Amphibians have evolved a huge variety of biologically active compounds to defend against predators and infection – and many of these hold the potential to be important for the development of new medicines (Chivian & Bernstein, 2008). More than 800 alkaloids (compounds with a wide range of pharmacological uses including as non-opioid analgesics), 200 antimicrobial peptides, several hundred bioactive peptides and a range of other novel compounds such as 'frog glue' (non-toxic, high bonding strength secretions with a range of applications in industry and medicine; von Byern *et al*., 2017) have been identified within amphibian species to date (Chivian & Bernstein, 2008; Daly *et al*., 2005). Some of these unique compounds cannot, as yet, be recreated in a laboratory setting. For example, the amphibian alkaloid compounds extracted so far seem to be created through the ingestion and uptake of alkaloids from ants, mites, beetles and millipedes (Daly *et al*., 2002). The extent and severity of amphibian declines are the largest of all vertebrate taxa, with an estimated 32–55% (best estimate: 42%) of all species classified as threatened with extinction (IUCN, 2017; **Figure 3.4a**). An estimated 168 amphibian species are thought to have gone extinct in the wild in recent years (Stuart *et al*., 2004), raising the very likely probability that many compounds potentially of use in human medicine have, or will soon vanish before being discovered. Other taxa identified with a significant number of potential sources of novel medicine include bears, sharks and horseshoe crabs (Chivian & Bernstein, 2008). While bioprospecting, wild harvesting and laboratory experiments on animals all carry their own drawbacks and ethical considerations, the utility of wild species to provide templates for novel avenues of research, synthesis of artificial compounds and inspiration for drug development cannot be ignored.

Ecosystem mediated effects on health

Nature and NCP can also impact human health through ecosystem level effects on the productivity of agricultural landscapes (dependent on pollinators), freshwater and ocean water quality, air pollution, the prevalence of zoonotic diseases, mental and physical health, and protection from natural disasters. These ecosystem-mediated impacts are central to several of the targets in SDG3 (and SDG 1 and 2). For example, declines of wild and domesticated pollinators are well documented (Potts *et al*., 2010). Pollination by insects is an important form of reproduction for at least 87 types of leading global food crop which make up over 35% of the annual global food production by volume, declines in the distribution and abundance of pollinators therefore have significant repercussions for both agricultural productivity and human nutrition (Klein *et al*., 2007; Whitmee *et al*., 2015). Depending on diet composition, in South-East-Asia up to 50% of plant derived sources of vitamin A require propagation through pollination while iron and folate have lower, but still significant pollinator dependence, reaching 12–15% in some parts of the world (Chaplin-Kramer *et al*., 2014; Ellis *et al*., 2015). A recent modelling exercise calculated that if worldwide declines in pollinators resulted in a 50% loss of pollination services from the food supply chain, that the impacts of reduced availability of vitamin A and folate could increase global deaths yearly from non-communicable and malnutrition-related diseases by c. 700,000 and disability adjusted life-years (DALYs) by c.13.2 million (Smith *et al*., 2015).

Target 3.2: By 2030, end preventable deaths of newborns and children under 5 years of age, with all countries aiming to reduce neonatal mortality to at least as low as 12 per 1,000 live births and under-5 mortality to at least as low as 25 per 1,000 live births.
Approximately 80% of diarrheal disease — the second leading global cause of death of children under the age of five — is attributable to unsafe water and insufficient hygiene and sanitation (Prüss-Üstün *et al*., 2008). This diarrheal disease burden is disproportionately experienced by low- to middle-income countries, particularly in sub-Saharan Africa, Southeast Asia, Latin America and the western Pacific (Prüss-Üstün *et al*., 2014). Addressing this problem requires a systemic approach focused on improving sanitation, hygiene and water access while also decreasing pollution from land management practices (Myers *et al*., 2013). Diarrhea is both a water-borne and water-washed disease with clear links to SDG 6 (i.e., both water quality and water quantity is key) (UNICEF, 2006).

UNICEF (2005) estimates that 3 billion people lack access to sanitation facilities and another 1.3 billion lack access to improved water sources. Inadequate access to water, sanitation, and hygiene is already estimated to cause 1.7 million deaths annually and the loss of at least 50 million healthy life years (Myers & Patz, 2009). As a result, rural populations directly rely on rivers, streams, lakes and ponds, and, therefore, on NCP to provide clean, ample water for consumption, sanitation, and hygiene. Forested watersheds play an important role in maintaining water quality, enhancing water use efficiency, and stabilizing the hydrological cycle (Lal, 1993). Natural forests may enhance river water quality by preventing soil erosion, trapping sediments, and removing nutrient and chemical pollutants, reducing microbial contamination (fecal coliform bacteria, cryptosporidium, fungal pathogens) of water resources, and preventing salinization (Cardinale *et al*., 2012; WHO & CBD, 2015 and references therein). Upstream tree cover is associated with a smaller probability of diarrheal disease downstream in rural communities (Herrera *et al*., 2017; Pienkowski *et al*., 2017).

Plant and algal species diversity enhances the uptake of nutrient pollutants from water and soil (e.g., Cardinale *et al*., 2012), and water purity is enhanced by some animal (such as the copepod *Epischura baikalensis* in Lake Baikal, Russia; Mazepova, 1998) and plant species (e.g., *Moringa oleifera* seeds and *Maerua decumbens* roots are used for clarifying and disinfecting water in Kenya; PACN, 2010). In marine ecosystems, numerous scientific studies have shown that filter feeders play an important role in water purification and elimination of suspended particles from water (Newell, 2004; Ostroumov, 2005, 2006). Bivalve molluscs of both marine and freshwater environments have the ability to filtrate large amounts of water (Newell, 2004; Ostroumov, 2005). Molluscs may also reduce pharmaceuticals and drugs from urban sewage (Binellia *et al*., 2014). One mussel species of Chilean and Argentinean freshwater habitats, *Diplodon chilensis chilensis* (Gray, 1828) plays a key role in reducing eutrophication, both by reducing total phosphorus (PO4 and NH4) by about one order of magnitude and also by controlling phytoplankton densities. Mangrove wetlands have also been shown to remove heavy metals from water (Marchand *et al*., 2012). Yet, habitat degradation and biodiversity loss often continue to hamper the ability of ecosystems to provide water purification services.

The impacts of trends in nature and NCP on water resources and therefore diarrheal disease burden depend on many ecological and socioeconomic factors, making generalizations difficult (we therefore assign mixed or uncertain status to this target in **Figure 3.13**). Natural factors include climate, topography and soil structure, while socioeconomic factors include economic ability and awareness of the farmers, management practices, and the development of infrastructure. In the case of forest systems, the precise impact of catchments on water supply varies dramatically between places and in relation to age and composition of the forest (Stolton & Dudley, 2003). There appears to be a clear link between forests and water quality, a much more sporadic link between forests and water quantity, and a variable link between forests and flow regulation (Stolton & Dudley, 2003).

Target 3.3: By 2030, end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases.
Infectious diseases are caused by pathogenic microorganisms, such as bacteria, viruses, parasites or fungi and can be spread, directly or indirectly, from one person to another (WHO, 2017). Most infectious diseases are zoonotic, i.e. they originate from or have a reservoir in wild or domestic animals (Redding *et al*., 2016). Zoonotic diseases are a significant source of threats to human health, with vector-borne diseases accounting for more than 17% of all infectious diseases and causing more than 700,000 deaths annually (WHO, 2017) and zoonoses originating in vertebrates such as birds, bats and dogs with a 'spillover' effect to humans have caused some of the biggest public health crises of the 21st century – for example the 2014–2015 Ebola epidemic in West Africa (Plowright, 2017) which caused a confirmed 11,310 deaths (although many more are suspected; WHO, 2016) and the H1N1 influenza outbreak (also known as swine flu) in 2009 which caused an estimated 284,500 deaths (Dawood *et al*., 2012).

Complex links between increased human disturbance, land-use change, habitat loss/degradation and biodiversity loss have all been linked to increases in the prevalence and risk of zoonotic disease for a variety of pathogens (Whitmee *et al*., 2015; WHO & CBD, 2015). Causal mechanisms are only well known for a handful of infectious diseases and it is sometimes hard to pick apart the drivers of disease to isolate the direct effects of environmental change from other human actions (Table S3.5). In addition, synergistic effects from other aspects of global environmental change such as the overextraction of water, climate change and the introduction of invasive alien species may also exacerbate disease prevalence and risk (Table S3.5; Hosseini *et al*., 2017; Ostfeld, 2017; Pongsiri *et al*., 2009). We therefore assign an uncertain status to this target indicating this knowledge gap around the trends in nature and their implications for infectious disease **(Figure 3.13)**.

Relationships between biodiversity and disease are multi-directional, with both positive and negative relationships being reported, that is, high biodiversity has been reported to increase and decrease the risk of zoonotic spillover and exposure to vector-borne zoonotic diseases (CBD, 2015; Faust *et al*., 2017). A long-held theory, known as the 'dilution effect', states that declining biodiversity increases disease transmission with the rationale that greater host diversity provides a higher proportion of low competent hosts or provides increased host regulation (aka predation) and therefore 'dilutes' the transmission chain (Faust *et al*., 2017; Keesing *et al*., 2006). Under this assumption intact habitats, high diversity and natural communities can provide protection against disease transmission. However, the impacts of species loss on disease are not straightforward (Dirzo *et al*., 2015). Following a review of recent literature, Wood *et al*. (2014) argue that "conditions for the dilution effect are unlikely to be met for most important diseases of humans. Biodiversity probably has little net effect on most human infectious diseases but, when it does have an effect, observation and basic logic suggest that biodiversity will be more likely to increase than to decrease infectious disease risk" – the so called 'amplification effect'.

Jones *et al*. (2008) found that mammalian biodiversity was a significant predictor of zoonotic spill-over, suggesting that biodiversity contributes to disease emergence risk in conjunction with other socioeconomic and environmental factors. One potential mechanism for this is that areas with high biodiversity may play host to a larger pool of pathogens with the potential to infect humans (Murray & Daszak, 2013). However, evidence supporting this assumption is variable; pathogen diversity and the ability of a pathogen to infect humans seem to differ between taxa and location (Murray & Daszak, 2013; Ostfeld & Keesing, 2013). According to Levi *et al*. (2016) some empirical examples do seem to demonstrate amplification, and certainly patterns are not simple (e.g., Young *et al*., 2013 found no evidence that biodiversity conservation generally reduces the risk of infectious disease in primates). Allen *et al*. (2017) showed globally zoonotic emerging infectious disease risk (EID) risk is elevated in forested tropical regions experiencing land-use changes and where mammal species richness is high.

As both empirical and modelling work delve deeper into these relationships it becomes clear that transmission mode, host and community relationships, host attributes relating to transmission, scaling relationships with area all have to be considered when trying to understand the mechanisms and context-dependence of biodiversity-disease relationships in order to identify how biodiversity loss will affect human disease. Recent modelling work by Faust *et al*. (2017) found evidence for dilution and amplification effects with frequency-transmitted pathogens (pathogens where the proportion of hosts or vectors infected is thought to influence transmission) and amplification effects alone were detected for density-dependent pathogens (pathogens that are transmitted through random contact among individuals or by aerial transmission). Further pathogen-specific research, studies examining suites of diseases in conjunction and placing both impacts and benefits from biodiversity within the broader context of socioeconomic driving forces are needed before these relationships are understood in enough detail to inform conservation policy (Young *et al*., 2017).

We are not able to assess a trend in nature or NCP relevant to this target **(Figure 3.13)**, but in the Supplementary Materials we explore specific diseases of relevance to the target and provide some evidence of impacts of nature and NCP trends on these diseases.

Target 3.4: By 2030, reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being.

The links between nature and mental health and well-being is a new area of focus for research and practice (e.g., Brattman *et al*., 2012; 2015).

The positive effects of time spent in natural environments include better mental health, stress reduction, improved cardiovascular health and social and cultural benefits such as community satisfaction, and reduced social problems (CBD, 2015 and references therein; Chivian & Bernstein, 2008). Green space and tree canopy percentage have also been found to have a positive effect on mental health in some studies, for example in Wisconsin increased green space in neighborhoods was found to be associated with significantly lower levels of depression, anxiety and stress symptoms (Beyer *et al*., 2014). Increased neighborhood green spaces reduce both morbidity and mortality from many cardiovascular and respiratory diseases and stress-related illnesses (Smith *et al*., 2014). Tree canopies have a higher albedo effect than other hard surfaces and can work to reduce the urban heat island effect, lowering heat mortality by 40–99% (Stone *et al*., 2014). Benefits of interaction with nature have been shown for relationships including domestic animals, and wild animals in wild settings in treatments for depression, anxiety and behavioural problems, particularly in children and teenagers (CBD, 2015 and references therein). A systematic review of benefits to health from exposure to natural environments reported that significantly lower negative emotions, such as anger and sadness, were experienced after exposure to a natural environment in comparison with a more synthetic environment in a subset of studies where these were measured (Figure S3.2; Bowler *et al*., 2010). But as this work is new, with limited generalized findings on the relationships between nature and mental health, we note this as a knowledge gap and do not assess progress to this target **(Figure 3.13)**.

"Solastalgia" is a type of distress associated with environmental change caused by degradation of a familiar environment (Albrect *et al*., 2007). The extent and consequences of this condition are not well researched as yet, although an "Environmental Distress Scale" has been proposed to support further quantitative studies (Higginbotham *et al*., 2007).

Target 3.9: By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.

Many ecosystems can act as natural filters (e.g., wetlands) to help reduce levels of certain pollutants (sediment, N, P, heavy metals) from entering and flowing downstream in our watercourse (Birch *et al*., 2004; Klapproth & Johnson, 2009). Urban air pollution is driven by the combustion of fossil fuels for transport, power generation and other human activities (Stolton & Dudley, 2010). In 2012, 3.7 million deaths were attributable to ambient air pollution with about 88% of deaths occurring in low- and middle-income countries, primarily due to respiratory and cardiovascular disease (Lim *et al*., 2012; WHO, 2014). Healthy trees can help improve air quality and reduce large particulate matter (Nowak *et al*., 2006), but pollution removal rates by vegetation differ among regions according to the amount of vegetative cover and leaf area, the amount of air pollution, length of in-leaf season, precipitation and other meteorological variables (CBD, 2015). A review of studies that looked at the estimated health effects of pollution removal by trees and found some evidence for the role of woodlands and trees in reducing pollution and thus reducing the impacts of pollution on human health, although effect sizes tend to be small, with woodlands in UK helping prevent 5–7 deaths per year, and avoided mortality of around 1 person per year per city in 10 US cities (but reaching as high as 7.6 people per year in New York City) (CBD, 2015 and references therein). There is also evidence that exposure to microbial communities in green spaces can reduce future allergy incidence (Ruokolainen *et al*., 2018).

While trends in key ecosystems such as wetlands or urban forest are relevant, the complex linkages between drivers of pollution, ecosystems as filters, and the resultant health outcomes prevent an assessment of relevant trends in nature for this target.

SDG 11: Sustainable Cities and Communities

Goal 11 of the SDGs aims to make cities safe, inclusive, resilient and sustainable. Nature and NCP will play a role in achieving this goal through the contributions they provide to city populations from local and regional areas including food, water, waste removal and other non-material contributions e.g., recreation. At the same time cities have a large impact on nature and NCP (within and outside the city) with clear linkages to multiple other SDGs. For a subset of targets under SDG 11 there are strong linkages to nature and NCP which we explore here.

Cities constitute a very small percentage of the total surface area of the planet's landscape, estimated at 2–3%, but have regional footprints that are much larger (Gaston *et al*., 2013; Schneider *et al*., 2010). This area and its footprint are projected to grow in the future, with cities holding approximately 60% of the world's population by 2030 and approximately 70% by 2050 (Seto *et al*., 2011; Sukhdev, 2013). A significant proportion of urban growth has occurred and will continue to occur in regions designated as "biodiversity hotpots" (Sukhdev, 2013).

Urban sustainability actions connected with SDG 11 to reduce pollution and increase green space availability and accessibility are relevant to nature, as well as NCP, (Schwarz *et al*., 2017). Green spaces in or near cities provide essential contributions (clean air and water, thermoregulation, and cultural benefits) (Sukhdev, 2013).

Target 11.3: By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.

Tracking progress to this target requires trends in urbanization impacts on nature and NCP, as well as trends in planning and management responses. High-density urban core areas in biodiversity hot spots increased by approximately 283,000 km^2, accounting for approximately 38% of the total global increase. Lower-density peri-urban areas increased by approximately 157,000 km^2, accounting for approximately 35% of the total global increase. This net gain in urban built-up areas in these ecologically critical zones came mostly at the expense of rural areas, which experienced a net decrease of approximately 277,500 km² (31%) in area, reducing available farmlands surrounding urban cores. These trends, as well as impacts on nature and NCP due to urbanization in section 3.2, suggest that progress to this goal is negative. As for future trends, based on projected growth under a business-as-usual fossil fuel driven scenario, global urban population within designated biodiversity hotspots will increase to approximately 1.85 billion by 2030 and 2.27 billion by 2050, with the most rapid rate of growth occurring in Africa (Jones & O'Neill 2016). The dramatic expansion in the anthropogenic footprint on the landscape in critical zones creates challenges for achieving SDG 11 targets with respect to nature and NCP due to habitat conversion and fragmentation.

Sustainable urban planning is essential to meeting this target as it will not only lessen the adverse effects of urbanization (e.g., habitat fragmentation, heat island effect, impervious surfaces, invasive species, pollution, etc. (Ma *et al*., 2018)), but also preserve and restore nature and NCP (e.g., green and blue spaces and urban ecological infrastructure) (Li *et al*., 2017). Urban planning is beginning to recognize the previously discounted values of nature and NCP by identifying areas in need of preservation and restoration, but the adoption of common standards, such as the City Biodiversity Index established in 2010, appears to be lagging and uneven (Convention on Biological Diversity, 2015). From a sustainable planning perspective there is progress towards the target but at an insufficient rate**,** due in part to either not knowing how to incorporate nature and NCP into city planning or that not enough cities have made the effort to do so **(Figure 3.13)**. Recent progress remains difficult to assess objectively but appears mixed due to a general lack of assessments based on common frameworks (e.g., CBI) especially for regions projected to experience rapid urban growth in the near term. Such efforts will be increasingly important over the coming decades, as total urban area is projected to increase by as much as 60% by 2030 (Elmqvist *et al*., 2015). Urban commons are particularly under increasing pressure (Derkzen *et al*., 2017), partly due to the growing power of "those who have a less direct relationship to nature's contributions to people for their livelihoods" (Rice *et al*., 2018: 34).

The interdependence of cities and local as well as regional ecosystems therefore compels reconsideration of conventional methods and the adoption of an integrated systems perspective recognizing cities as coevolving human-environment systems (McPherson *et al*., 2016; Wu, 2014). Progress in establishing general baselines established by cities themselves is therefore difficult to assess especially for most of Africa, Asia, and Latin America.

Urban sustainability objectives can be realized through governance mechanisms (administrative, judicial, and legislative) with input from civil society organizations (NGOs, activist groups, etc.) operating locally and in some cases in coordination internationally through umbrella organizations and networks focused on sustainability issues. SDG 11 highlights the importance of inclusive urbanization and planning. The engagement and involvement of local governance in implementing sustainability-oriented measures will be critical to the attainment of Target 11.3 and requires partnerships with local stakeholders. Achieving meaningful results requires engaging local actors and groups in "initiatives informed by open, inclusive and contextually sensitive data collection and monitoring" (Klopp & Petretta, 2017: 92). Further, achieving Target 11.3 will take the integration of the perspectives of both the natural and social sciences (Niemela, 2014), as well as giving proper consideration to "informal greenspaces" and a wide range of cultural groups and demographic cohorts (Botzat *et al*., 2016).

Target 11.4: Strengthen efforts to protect and safeguard the world's cultural and natural heritage. There is underdeveloped literature connecting the preservation of cultural and natural sites of designated heritage value with nature, NCP and GQL. Safeguarding cultural and natural heritage sites enjoys widespread support as embodied in the UNESCO "Convention on World Heritage" (1972). This shared objective is reaffirmed by target 11.4 and falls within the domain of non-material contributions from nature which encompass aesthetic values, educational opportunities, nature interactions, and recreation, and promotes cognitive development. Challenges with non-material contributions (chapter 2.3) therefore apply to this target including a lack of appropriate data, indicators and evidence. Relevant proxy measures identified include aesthetics, cultural heritage, recreational/touristic value, religious and spiritual value, and sense of place (La Rosa *et al*., 2016: 74, 84–85). A "Cultural Capital framework" has been proposed by economically oriented scholars, who recognize the impossibility of quantifying such heritage sites in strictly monetary terms (Wright & Epplink, 2016).

Progress toward attainment of this target is difficult to assess but can be characterized as inadequate but uneven on the basis of geographic and socioeconomic factors **(Figure 3.13)**. Poor progress is based on the assessment of sites characterized as endangered by the UNESCO "List of World Heritage in Danger" registry - over 50 of more than 450 sites are currently highlighted (Turner *et al*., 2012). Scholars have called for the scientific community to engage with local community members to leverage traditional knowledge relevant to the preservation of such cultural and natural heritage sites (Fatoric *et al*., 2017). Doing so will be critical to developing the adaptive capacity necessary to deal with climate change effects on urban centers and may also foster capacity-building by promoting an "exploration of interactions between social and ecological processes" (Horcea-Milcu *et al*., 2016). In this sense, the social processes associated with the preservation of historic sites may function in a transitive, enabling role *vis-à-vis* the maintenance of ecosystems and ecosystem services.

Target 11.5: By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations.

Nature can help protect against natural disasters. Ecosystems in coastal region, mangroves, salt marshes, and coral reefs can attenuate waves and reduce damage from storm, flooding, and erosion events (Barbier *et al*., 2011; Narayan *et al*., 2016; Spalding *et al*., 2014). Coral reefs and salt marshes have highest overall wave attenuation potential. Researchers have found that intact salt marsh and mangroves can be two to five times cheaper than submerged breakwaters (Narayan *et al*., 2016). As the assessment in SDG 14 indicated, all of these coastal habitats have been found to experience declines in extent and condition (Deegan *et al*., 2012; Hughes *et al*., 2018; Richards & Friess, 2016; Valiela *et al*., 2001), suggesting that efforts to use nature and NCP to protect coastal infrastructure and people are jeopardized by degradation of these ecosystems. These trends are likely worse in cities and in areas experiencing urban growth.

Similarly, floodplains and intact river catchments can similarly protect from river flooding events by diverting and holding excess water (Royal Society, 2014). In many regions, forests improve surface soil protection and enhance soil infiltration, prevent soil erosion and landslides, protect riverbanks against abrasion, and regulate microclimate (CBD, 2012; Naiman & Décamps, 1997) Analyses of flood frequency in low-income countries have found that the slope, amount of natural/non-natural forest cover and degraded area explain 65% of variation in flood frequency (Bradshaw *et al*., 2007), and is linked to the number of people displaced and killed by such events, though associations with larger flooding events linked to extreme weather are not conclusive (van Dijk *et al*., 2009). As evidenced by the assessment is SDG 6 and SDG 15, many of these habitats are similarly declining, decreasing their potential to control inland flooding, hence progress to this target is likely negative and insufficient **(Figure 3.13)**.

Target 11.6: By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management.

As discussed under Target 3.9 ecosystems can act as natural filters and help to reduce levels of certain pollutants in water (e.g., heavy metals) and to improve air quality by reducing large particulate matter. Findings from US cities point to avoided mortality of around 1 person per year per city in 10 US cities (but as high as 7.6 people per year in New York City) (CBD, 2015 and references therein). Trends in air quality and waste are available and are highlighted as negative with poor progress (**Figure 3.13**; SDG 3, 6). This will have implications for the environment and hamper progress to this target's aim to reduce these impacts, also highlighted in section 3.2 (see Supplementary Materials).

As highlighted in Target 3.9, pollution removal rates by vegetation differ among regions according to the amount of vegetative cover and leaf area, the amount of air pollution, length of in-leaf season, precipitation and other meteorological variables. Particulate matter is a year-round concern but more so during the winter months, when leaf cover is lost during the autumn until it returns in the spring (Escobedo *et al*., 2011). The perceived need to address air quality has motivated informal greening initiatives at the community level (Gómez-Baggethun *et al*., 2013a). Urban greening and the deployment of green infrastructure can contribute significantly to reducing the adverse airborne impacts of cities (Pitman *et al*., 2015). Urban trees and hedges can lessen air pollution through the uptake of pollutants while providing additional regulating services relating to carbon, soil, and water that benefit both humans residing in these cities and non-human species that co-occur with certain species of trees (Roy *et al*., 2012). Reductions in PM may range from as low as 9 per cent to as high as 50 per cent (Nowak *et al*., 2006). Pataki *et al*. (2011) caution that the outcomes of green infrastructures may vary widely and therefore endorse small-scale projects for evaluation, e.g., neighborhood scale. When initial results in favorable outcomes with respect to air, water, temperature, and health effects, projects can be scaled up for further evaluation at the municipal level.

Target 11.7: By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities.

This target seeks to extend green space, especially to those segments of the population considered most vulnerable. Achieving this target involves overcoming societal and spatial constraints. It also requires efforts focused on both nature and NCP within cities, with defined and measurable sub-targets that have generally been lacking in urban planning to date (Nilon *et al*., 2017). Studies conducted in Chile, Great Britain, India, Italy, Japan, Korea, and the United States, found disparities in Urban Green Space (UGS) access for different groups of people, where minorities and poorer populations tended to have lesser access. These studies employed spatial statistical methods to assess disparities in the supply of UGS relative to the level of demand by residents, where proximity affects accessibility (Comber *et al*., 2008; Dai, 2011; La Rosa *et al*., 2018; Lee & Hong, 2013; Rojas *et al*., 2016). This highlights insufficient progress to improved green space access captured in **Figure 3.13**.

The literature elaborates a wide array of benefits of green (and blue) spaces (see SDG 3, and section 3.3.2.3). The urban heat island effect, caused by the prevalence of urban materials that absorb and retain solar energy, increases exposure of residents to extreme heat and elevates the level of heat stress in all living organisms. Green space can provide relief from heat stress to those populations who otherwise lack access to intensive energy amenities such as indoor air conditioning (Gunawardena *et al*., 2017). In addition to avoiding heat-stress exposure, the promotion of green space and better access to green space is well-supported by a number of studies that identify potential health benefits associated with physical activity and social interaction (Gómez-Baggethun *et al*., 2013b; Kabisch *et al*., 2017; Lee & Maheswaran, 2011; van den Bosch & Sang, 2017). Urban settings inherently present challenges that correlate with elevated morbidity and mortality. It has been generally well established that reduced levels of physical activity associated with urban living are positively correlated with an increase in health issues such as cancer, cardiovascular disorders, chronic respiratory diseases, diabetes, obesity, and some mental conditions (van den Bosch & Sang, 2017). Challenges remain for trying to ensure access and public participation and the degree of space availability to develop them (see Supplementary Materials).

3.3.2.3 Cluster 3: Good Quality of Life (SDGs 4, 5, 10, 16)

SDG 4: Quality education

Evidence has shown that environmental education has a positive impact on the knowledge and actions required to help protect biodiversity (Moss *et al*., 2017). However, these results come from surveys of visitors to zoo and aquaria across the world and there is limited evidence to show that the same results would occur in those people with limited access and opportunities to visit such places. Many educational interventions promoting pro-environmental behaviour with children have shown positive results for enhancing stewardship behaviour and nature (Barthel *et al*., 2018; Cheng & Monroe, 2012; Grimmette, 2014) and there is increasing evidence of the role of meaningful nature experiences and pro-environmental behaviour (Ives *et al*., 2017; Miller, 2005; Raymond *et al*., 2010a). There are examples of best practice on education for sustainable development where positive outcomes have been shown (UNESCO, 2012).

Achievement of Target 4.7, which aims for people to acquire the knowledge and skills needed to promote sustainable development, should have a positive impact on nature and NCP (Leadley *et al*., 2014) and achievement of this goal should have far-reaching impacts for many of the SDGs (Figure S3.3). However, this relationship is not linear or simple as education and awareness levels increase globally (Leadley *et al*., 2014), environmental destruction over the last several decades is still occurring at a rapid rate (Cardinale *et al*., 2012; Steffen *et al*., 2017). Investment in environmental education has shown a general though non-significant decline in the last decade and Leadley *et al*. (2014) extrapolated that this will continue to 2020. Furthermore, inequality in access to quality education is a persistent problem.

At the higher level examining the relationship between nature, NCP and education, there is growing work and evidence on the role of access to nature and urban green space for achieving education outcomes (Mocior & Kruse, 2016) as well as in aspects relevant to education including cognitive function and mental health (e.g., Brattman *et al*., 2012, 2015). This is a promising area of future research, especially considering the knock-on effect of education on achievement of other SDGs (Figure S3.3).

SDG 5: Gender equality

There is increasing evidence that encouraging a gender focus on development can have positive impacts that address both gender inequalities as well enhance opportunities for nature and NCP conservation and sustainable use – which in turn can further reduce gender inequities (UNEP 2016d). There has been some progress in ensuring issues related to gender have been included in environmental policies, agreements, projects and programmes over the last several decades (e.g., the three Rio 92 Conventions on biodiversity, desertification and climate change and notably the 2030 Agenda on Sustainable Development which has achieving gender equity as a core goal (UNEP 2016d). These additions have been accompanied by increasing participation of women within these fora as country delegates, bureau members, NGO representatives; furthermore, funders of environmental projects have adopted gender mainstreaming activities in their activities.

The links between gender equality, nature and NCP are complex, context dependent and often a key knowledge and evidence gap **(Figure 3.10)**. Priority issues in promoting gender equality within this gender-and-environment nexus cut across SDGs. A priority issue revolves around access and rights to land, natural resources (NCP) and biodiversity. It has been demonstrated that secure land tenure (not necessarily ownership) is paramount to women's social, economic and political empowerment and achieving this enhances the prosperity of their families and communities (Klugman & Morton, 2013; Field, 2007; Sattar, 2012). However, despite this recognition, only 37% of 160 countries recorded in a study show that women have the same rights as men to own, use and control land (OECD, 2014) and while legislation in more than half of the countries in the study support equal rights for women, religious, customary and traditional barriers prevent gender equality, while in 4% of the countries, women explicitly have no legal right to own, use or control the land.

Another priority topic is women's participation in decision-making processes governing the use of nature and NCP

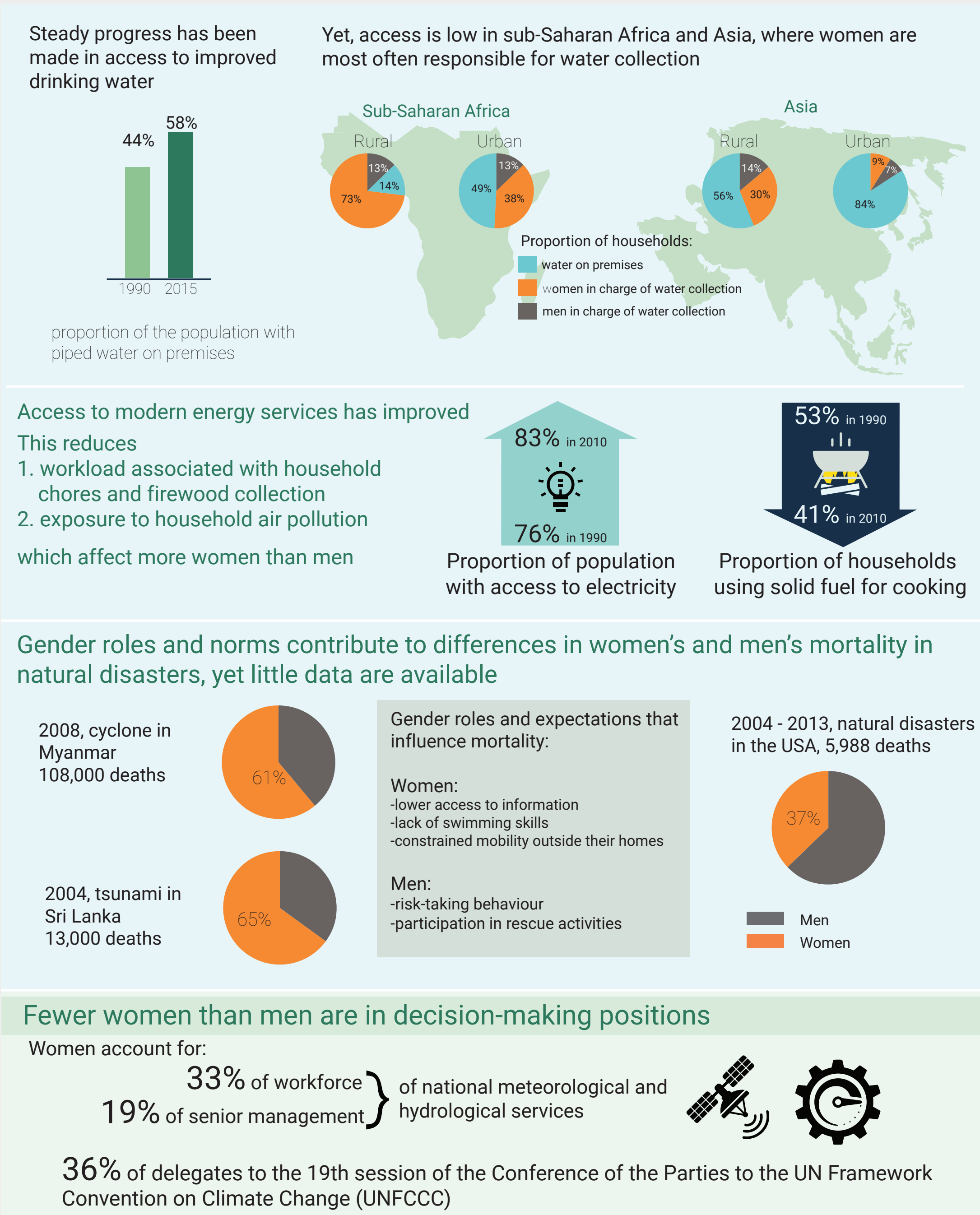


Figure 3 10 **The environment affects women and men differently due to gender inequality.**

Source: UNSD (2015).

has been shown to be fundamental for the sustainable management of those resources (Agarwal, 2010; Ray, 2007). While some studies have suggested potential win-win scenarios for women on average, there are often hidden trade-offs and negative impacts of changes in nature and NCP on women (Daw *et al*., 2015). In terms of biodiversity, notably agrobiodiversity, women play different roles to men, acting as custodians, users and adaptors of traditional knowledge which contributes to food security and seed and plant stock conservation for continued production (UNEP, 2016d). Policies regarding benefit-sharing and access to genetic resources have become increasingly important for marginalized groups as the global trend on privatization of biological resources increases which alters how women are able to use free and self-replicating seeds and the role they play in maintaining agricultural diversity, plant breeding, pest control, ecosystem management for resilience which is often undervalued and performed for free by women and girls (UNEP 2016d; Shiva 2016a).

Mainstreaming gender in development to promote access to and control over resources such land and production inputs, technology, information and innovation, has been shown to increase agricultural productivity, thereby reducing hunger and poverty with further links to many SDGs (UNEP 2016d). In both urban and rural areas, especially in informal settlements and low-income neighborhoods in the global south where basic infrastructure is often lacking, women and girls are more likely to have the primary responsibility for energy, water and sanitation management, with a disproportionate burden on them to produce and collect water, food and fuel (Grassi *et al*., 2015; UNSD, 2015). Although the role of biodiversity is indirect for this goal, it is clear that depletion of nature and NCP, increases the effort and travel distance required to access household necessities such as water, fuel wood, biomass and other forest products. The burden of this falls disproportionately on women and children. Reducing this burden through improved biodiversity management would free up time for other activities including education (Leadley *et al*., 2014).

Also, key to consider are how the impacts of global change, including climate change and biodiversity loss, exacerbate existing gender inequalities, jeopardizing future well-being opportunities with important implications for all SDGs and the intent to leave no one behind (Aguilar *et al*., 2015; Arora-Jonsson, 2011; Nightingale, 2006). A decrease in nature and NCP have gender differentiated impacts with women and girls most often being negatively impacted by these changes (UNEP, 2016d). The gender-differentiated consequences of climate change increases the burden on women to: seek alternative sources of food and income mainly from the utilization of nature and NCP (Bechtel, 2010; Momsen 2007), provide (unpaid) healthcare linked to disaster-related health risks and food and water insecurity (Babugura *et al*., 2010) and secure access to climate-smart agriculture programmes (UNEP, 2016d), often without supportive policy and enabling environments. Land degradation and water and air pollution as a result of the intensification of the use of chemicals in agriculture and industrial production has gendered impacts, with women being affected often to a larger degree than men (Prüss-Ustün *et al*., 2014; 2016). Prevailing assumptions that women control house-hold based consumption choices oversimplify power and gender dynamics related to consumption patterns and the gendering of consumer products increases demand of some products (UNEP, 2016d). This can have negative impacts on nature and NCP especially in relation to the trade of endangered species for cosmetic or medical purposes (Still, 2003). Mainstreaming a gender focus into decisions around natural resources would enable some of these gendered outcomes of local and intra-household dynamics to be more apparent, especially in light of rapid change. Institutional capacity and legal frameworks often inadequately reflect differential gender roles (UNEP 2016d).

Assessing progress to SDG 6, especially the role of nature and NCP in supporting progress, is hampered by a chronic shortage of gender disaggregated information, especially data on biodiversity access, use and control, the differential health impacts of biodiversity change, water use and sanitation, nature-based occupations and whether these occupations are carried out by indigenous women. As the term 'gender' is also often still used as a proxy for 'women' there is little analysis of power relations between men and women within households or society or how intersecting inequalities based on other social characteristics play out in natural resource governance, especially at a household level (Harris, 2011; UN Women, 2014).

SDG 10: Reduced inequalities

Reducing inequality is a cross-cutting issue underpinning the achievement of many of the SDGs in order to leave no one behind (ISSC, 2016; Oxfam, 2017; Piketty & Saez, 2014). Inequalities are multi-dimensional, multi-layered and cumulative (Figure S3.4). Furthermore, inequality, nature and NCP interact in a number of different (and often poorly understood) ways. The majority of research that has looked at these connections considers mainly one-directional linkages between inequality and nature whereas the connections between nature, NCP and inequality are complex, with multiple positive and negative feedbacks, making the achievement of this goal challenging. Most analyses of the relationship between nature, NCP and inequality have focused on economic inequality (e.g., poverty levels) and how it impacts particular environmental variables at a national scale (Berthe & Elie, 2015; Cushing *et al.,* 2015), with limited studies highlighting issues related to other manifestations of inequality such as those relating to gender, education levels, age and other social variables (Hamann *et al*., 2018). In terms of how changes in nature and NCP affect inequality, most of the studies have looked at the impacts of climate change and associated extreme events (Hallegatte *et al.,* 2016; IPCC, 2012; Mendelsohn *et al.,* 2006).

Inequality between communities and people can be amplified or reduced by both sudden and slower incremental changes in nature and NCP (Hamann *et al.,* 2018). Sudden changes in nature and NCP linked to extreme events such as floods, droughts, storms and wildfires have been shown to exacerbate existing inequalities in vulnerable and marginalized communities (IPCC, 2012; Pelling *et al.,* 2002; Turner *et al.,* 2003), especially those already living in degraded landscapes where regulating functions of nature have been eroded (Adger *et al.,* 2005). Other abrupt environmental shocks such as epidemics of zoonotic and epizootic diseases can also enhance inequality through impacting human and livestock health and associated social and economic investments (Elston *et al.,* 2017; Morens *et al*., 2004; Ordaz-Németh *et al.,* 2017). Failure to address the underlying vulnerabilities of communities that rely on nature and NCP for survival and a good quality of life can result in these communities being 'trapped' in poverty should the frequency, duration and intensity of the environmental change overwhelm coping, adaptation or transformation capabilities (Barrett & Carter, 2013). Slower, incremental changes in biophysical variables associated with climate patterns and the distributions of species, notably agricultural (Hatfield *et al.,* 2011) and marine species (Gattuso *et al.,* 2015) can also result in increased inequality between people, communities and nations, as well as between individuals at local levels e.g., with gender-differentiated impacts (Béné & Merten, 2008; Harper *et al.,* 2013).

Inequality also affects nature and NCP indirectly through how it influences human activities and actions, which then positively or negatively affect or impact the quality and state of nature and flow of NCP. There is evidence of the links between inequality and decreasing levels of biodiversity (Holland *et al*., 2009; Mikkelson *et al*., 2007; Pandit & Laband, 2009), with varying evidence on how income inequality impacts environmental quality indicators such as CO_2 emissions, air and water quality (Berthe & Elie, 2015; Cushing *et al*., 2015; Grunewald *et al*., 2017; Hamann *et al*., 2018). A study by Hamann *et al.* (2018) outline how inequality affects nature and NCP through four pathways: perceptions and sense of fairness e.g., in the success or failure of marine protected areas (Chaigneau & Brown, 2016; Edgar *et al.,* 2014) or climate negotiations (Dubash, 2009), aspirations e.g., linked to changes in consumption patterns such as increases in meat consumption which has knock-on effects on local and global biodiversity (Ranganathan *et al*., 2016; Tilman & Clark, 2014), market concentration where asymmetries in resource control can impact the management of the resource such as in fisheries at national and global scales, and cooperation in sustaining the local commons which sees varying levels of inequality having different impacts on nature and NCP conservation depending on the local context (Hamann *et al.,* 2018).

Addressing issues related to equality and the SDGs through attention to distributional, procedural and recognitional aspects of inequality can enable marginalized groups and people to have a stronger voice and more positive outcomes in the decisions that affect nature and NCP (Leach *et al*., 2018).

SDG 16: Peace, justice and strong institutions

There are clear links between the condition and availability of nature and NCP to people and violent conflict (Rustad & Binningsbo, 2012; Schleussner *et al*., 2016; von Uexkull *et al*l., 2016). A review by Hanson *et al*. (2009) highlighted that over 90% of the armed conflicts that took place between 1950 and 2000 were within countries containing biodiversity hotspots, and over 80% of these conflicts occurred directly within hotspot areas. There remains a large gap in terms of our knowledge of the impacts of war on nature and NCP, especially from post-conflict zones in Africa (IPBES, 2018). However, evidence exists regarding the negative relationships between many activities associated with military forces, warfare and defense activities and nature and NCP such as those linked to: production and testing on nuclear weapons, aerial and naval bombardment, land mines, despoliation, defoliation and toxic pollution (Leaning, 2000). Wars and civil unrest generate feedbacks that reinforce and amplify interactions between and among resource availability, ecosystem vulnerability and violent conflict (Dudley *et al*., 2002). Thus, resolving natural resource conflicts has been identified as a precursor to sustainable development especially in unstable states (United Nations, 2002).

Scarcity of NCP e.g., drought has been linked to increases in violence in previously stable states (Bell & Keys, 2016). A report by UNEP on the role of natural resources and the environment in relation to conflict and peacekeeping, highlighted that around 40% of all conflicts within states in the last 60 years can be linked directly to natural resources, and that the exploitation of natural resources has powered and contributed financially to approximately 18 conflicts since 1990 (UNEP, 2009). However, not all of these conflicts have been linked to nature or NCP and have centered on conflicts related to mineral resources. Material NCP have been shown to be the most common cause of conflicts (see **Table 3.6**; Ross, 2003; UNEP, 2009), and often it is nature and NCP that is affected following conflict as people and communities attempt to rebuild local livelihoods and satisfy basic human needs. For example, conflicts in the Middle

Table 3 6 **Recent civil wars and internal unrest fuelled by natural resources.**

Source: UNEP (2009).

Country	Duration	Resources
Afghanistan	1978-2001	Gems, timber, opium
Angola	1975-2002	Oil, diamonds
Burma	1949-	Timber, tin, gems, opium
Cambodia	1978-1997	Timber, gems
Colombia	1984	Oil, gold, coca, timber, emeralds
Congo, Dem Rep. of	1996-1998, 1998-2003, 2003-2008	Copper, coltan, diamonds, gold, cobalt, timber, tin
Congo, Rep. of	1997-	Oil
Côte d'Ivoire	2002-2007	Diamonds, cocoa, cotton
Indonesia – Aceh	1975-2006	Timber, natural gas
Indonesia – West Papua	1969-	Copper, gold, timber
Liberia	1989-2003	Timber, diamonds, iron, palm oil, cocoa, coffee, rubber, gold
Nepal	1996-2007	Yarsagumba (fungus)
PNG - Boungainville	1989-1998	Copper, gold
Peru	1980-1995	Coca
Senegal – Casamance	1982-	Timber, cashew nuts
Sierra Leone	1991-2000	Diamonds, cocoa, coffee
Somalia	1991-	Fish, charcoal
Sudan	1983-2005	Oil

East in Syria, Lebanon, Palestine and Israel and Yemen have all shown a reduction in nature and NCP following or during ongoing conflicts, with most of these conflicts having devastating effects on human well-being and food and water security because of their long-lasting disruption of the productive base, and its impacts on overall well-being (UNEP, 2016; Weisman, 2006). Consequently, those countries involved in conflict, and those with higher levels of inequity experience higher levels of food emergencies (Teodosijević, 2003).

The development of effective, accountable and transparent institutions (target 16.6) and broadening and strengthening the participation of developing countries in the institutions of global governance (target 16.8) can help reduce the impacts of unrest on nature and NCP. Enhancing governance mechanisms through this goal and associated targets can also reduce the negative social and ecological impacts of unregulated transnational land acquisitions (land grabbing) which are occurring at increasing rates in all continents except Antarctica (Rulli *et al*., 2013; **Figure 3.11**). The global increase in the demand for agricultural land often results in large scale land acquisitions directly and indirectly contributing to land degradation and deforestation which is occurring at increasing rates in the affected countries as much of the land was not used for agriculture but was savanna or forest ecosystems (Koh *et al*., 2008). Thus, these large scale land acquisitions have significant impacts on nature and NCP, and further undermining the ability to achieve many of the SDGs linked to food and water security, reducing inequality and promoting a good quality of life (Borras *et al*., 2011; Tscharntke *et al*., 2012).

Achieving SDG16 also means significantly reducing all forms of violence and related death rates everywhere (16.1). Those resisting the appropriation of tracts of land and water, notably indigenous and local community members and activists, have increasingly been targeted and killed over the last decade with most years reporting higher statistics than the previous year, signalling a worrying increase in attacks on environmental activists and nature defenders (Global Witness, 2018; Rowell, 1996; **Figure 3.12**).

The global trade in illegal wildlife has been valued between US$5 billion and US$20 billion a year and threatens biodiversity, nature and NCP and acts as a potential avenue for invasive species and disease spread (Rosen & Smith, 2010; Wyler & Sheik, 2008). Without strengthening and developing effective, accountable and transparent institutions at all levels to target organized crime syndicates

Figure 3 11 **A global map of the land-grabbing network: land-grabbed countries (green disks) are connected to their grabbers (red triangles) by a network link.**

Relations between grabbing (red triangles) and grabbed (green circles) are shown (green lines) only when they are associated with a land grabbing exceeding 100,00 ha. Source: Rulli *et al.* (2013).

WHERE ENVIRONMENTAL ACTIVISTS WERE KILLED 2010 TO 2015

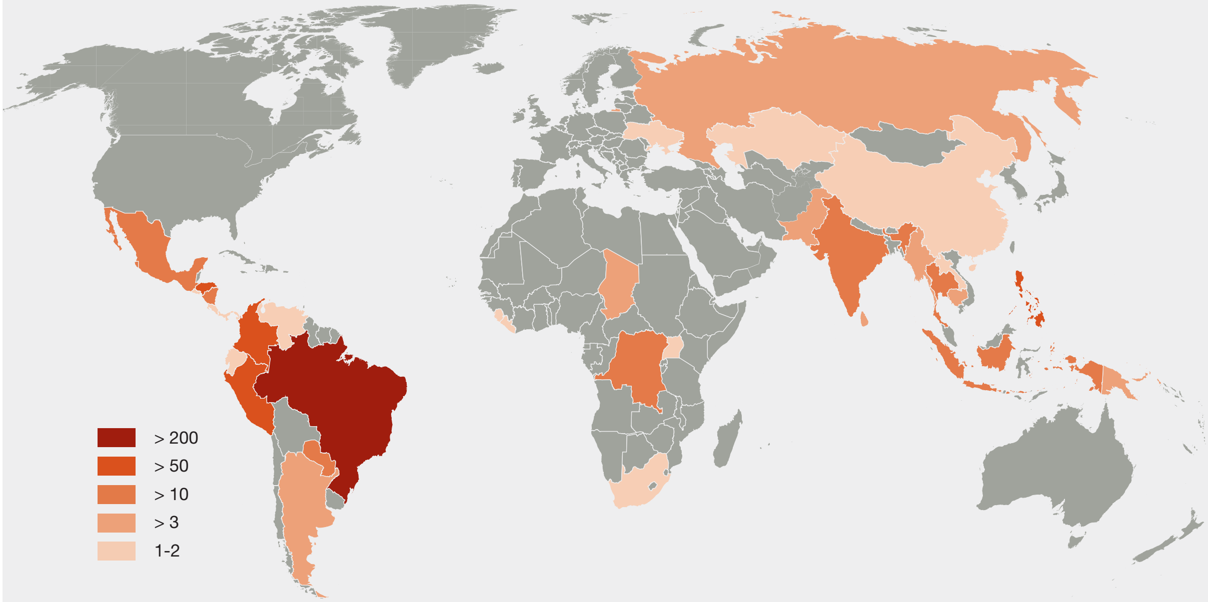


Figure 3 12 **Number of reported deaths of environmental activists during 2010-2015.**

Source: https://www.globalwitness.org/en/.

and tighten national and international cooperation to combat illegal wildlife trade (target 16.6) many populations of endangered species will continue to decline in the wild. Illegal trade in wildlife products has also been linked to financing the activities of militant groups and catalyzing social conflict (Douglas & Alie, 2014) and as the scarcity of rare and endangered species becomes more apparent, their rarity is likely to fuel more demand, increasing the potential for overexploitation and intensifying conflict dynamics.

In terms of enhancing the role of justice in the governance of nature and NCP, this has mainly been looked at in relation to addressing issues linked with inequality with a particular focus on more inclusive and fair protected area management by focusing on issues related to recognition (Martin *et al*., 2016), social justice (Vucetich *et al*., 2018), understanding and managing conservation conflicts (Redpath *et al*., 2012) and better understanding the role of social equity (Friedman *et al*., 2018). Notions of justice and nature have also been increasingly integrated in urban planning processes (see SDG 11.7), especially in relation to urban nature and NCP and their role in building resilience and addressing inequities (Dearing *et al*., 2014; Graham & Ernstson, 2012; Ziervogel *et al*., 2017).

3.3.2.4 Cluster 4: Drivers (Goals 7, 8, 9, 12)

Several SDGs have the potential to be negative or positive drivers of change in nature and NCP, depending on the pathways that are chosen to achieve them. Impacts from particular activities and economic sectors on nature and NCP, as well as trends in all of these, are detailed in chapter 2. Here, we briefly summarize how nature and NCP may be positively or negatively impacted by these SDGs.

SDG 7: Affordable and clean energy

Achievement of targets under SDG 7 can have both positive and negative impacts on nature and NCP. Clean energy should help to mitigate the impacts of climate change, which would have positive impacts on several SDGs including SDGs 1, 2, 3, 6, 13, 14, and 15. Key pathways to achieving clean energy will include developing wind, wave, and water-based (hydropower) energy projects. These developments can have positive or negative impacts on nature and NCP and related SDGs depending on how they are constructed. Dams can radically alter river flow regimes, affecting the function and productivity of downstream waters, which can negatively impact achieving targets within SDGs 6 and 15 related to aquatic ecosystems. However, recent research has found that careful monitoring of flows can be managed to ensure healthy fish stocks, a key concern for food security in some regions (Sabo *et al*., 2017). If not designed and constructed properly, wind and wave energy projects could affect the achievement of targets under SDGs 14 and 15. Clean energy may also include petroleum development projects, which may still negatively impact reduction of greenhouse gases associated with climate change.

SDG 8: Decent work and economic growth

Nature and NCP can provide pathways to achievement of SDG 8 but can also be positively or negatively impact by policies and measures implemented to achieve them (See SDG 1 for a discussion of economic growth, poverty alleviation and nature). Achievement of Target 8.4 on improvements in global resource efficiency would have strong positive impacts on nature and NCP by decoupling economic growth from environmental degradation. At the same time, nature and NCP provide pathways for achieving economic growth. Effective management of nature and NCP may provide greater employment opportunities and revenue generation. The forestry and fisheries sectors alone are worth at least $583 billion (FAO, 2014b) and $148 billion per year (FAO, 2016), respectively. Employment in sectors that depend on sustainable production in these ecosystems and others can also be critically important to national economies (FAO, 2014b; Jaunky, 2011).

There are recognized needs to initiate reforms in some ecosystem-based sectors to meet Target 8.7 (on ending slavery and child labour) and 8.8 (on labour rights and safe working environments). For example, the need to initiate reforms in the fisheries sector has received increased focus (Kittinger *et al*., 2017) as has the role of companies in improving practices along their supply chain (Österblom *et al*., 2015). Similarly, achievement of Target 8.9 could also have potential positive impacts on nature and NCP through the development of sustainable tourism. Implementation of activities to achieve many other targets under SDG 8 will need to consider how they may have impacts on nature and NCP and whether these can be mitigated or minimized. Future work should also consider the role of nature and NCP in creating decent work in new areas, as well as rights-based approaches to employment and job creation.

SDG 9: Industry, innovation and infrastructure

Achievement of SDG 9 targets can have either positive or negative impacts depending on approach, although the potential for large negative impacts appears high. Efforts to develop quality reliable infrastructure in Target 9.1 could include developing public transportation systems and enhancing rail networks, both of which would have positive impacts in the achievement of SDG 13 by mitigating climate change, with consequent indirect positive impacts on SDGs 6, 14, and 15. However, indicators for Target 9.1 suggest that road-building would also be a major aspect of achieving Target 9.1. Roads can be a major source of habitat fragmentation with negative impacts for ecosystems (Pfeifer *et al*., 2017) and species like birds and mammals (Benitez-Lopez *et al*., 2010). Roads are also associated with increased deforestation in the Amazon (Barber *et al*., 2014). Similar potential positive and negative impacts could be associated with the development pathways that may be chosen for Targets 9.2 (promote sustainable industrialization) and 9.3 (increase access of small-scale industries to financial services). Target 9.4 (upgrade infrastructure and retrofit industries to make them more sustainable) is likely to have positive impacts on nature and NCP by making industries more sustainable and cleaner, with lower CO_2 footprints. Achievement of Target 9.5 (Enhance scientific research and upgrade technological capabilities of industrial sectors) may also have positive impacts through the development of technology that reduces industrial footprints, identifies opportunities for circular economies, or improvement to supply chains.

SDG 12: Responsible consumption and production

Meeting the targets under Goal 12 has the significant potential to have positive impacts on nature and NCP by changing production and consumption patterns. Target 12.2 on resource use, target 12.4 on waste management, target 12.7 on procurement practices, and target 12.8 on information and awareness of sustainable development are particularly relevant to efforts to conserve and sustainably manage nature and NCP.

Target 12.2 is fundamental to the notion of sustainable development and development's reliance on renewable and non-renewable land, ocean, water and nature resources. Their exploitation is linked to positive impacts on well-being on average, but negative implications for nature and NCP, as well as unequal and negative impacts on certain groups, places and generations (WSSD, 2002). The scale of human impacts now implies that the effects of not achieving this target will be globally realized e.g., through climate change, shifts in biogeochemical pollutant loads and the loss of biosphere resilience (Steffen *et al*., 2015). This target has overlaps with several targets in SDG 15 on conservation, sustainable management and resource use. The concept of efficient use has some potential but requires clarification and standards emerging from fields such as Life Cycle Analysis and others in order to make it measurable and the challenges of incommensurability of inputs and outputs may prove an obstacle. This would be challenging especially in the light of IPBES's embrace of multiple values implying that an economic analysis to efficiency would be insufficient.

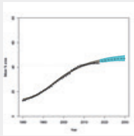
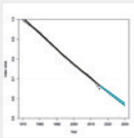
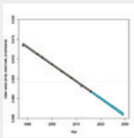
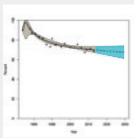
Target 12.4 on waste management is an area likely to have many positive implications on nature and NCP as well as GQL of all people. Currently waste, through its impacts on air and water quality, has negative impacts on well-being, especially in poor and vulnerable communities. This target relates closely to SDGs 6, 14, and 15, as well as aspects of SDG 3 and 11, in terms of trends in pollution and its impacts on health and the environment. Recent work on chemical pollution has highlighted what are referred to as "novel entities" – created entirely by humans e.g., synthetic organic pollutants, radioactive materials, genetically modified organisms, nanomaterials, and microplastics. These have important implications for nature and people, they can exist for a very long time, and their effects are potentially irreversible (Steffen *et al*., 2015).

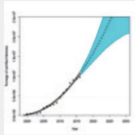
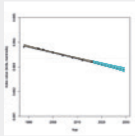
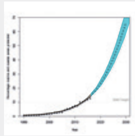
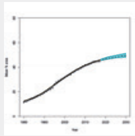
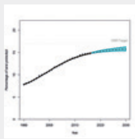
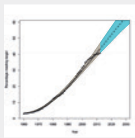
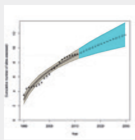
Target 12.7 focuses on public procurement which is widely recognized as a way to achieve GQL outcomes, including those linked to sustainability (McCrudden, 2004). There have been documented successes in terms of addressing equality and human rights (McCrudden, 2004). Achievement of this target could benefit nature and NCP by only sourcing materials that were harvested sustainability or produced with minimal impact in the supply chains used by public entities. The considerable buying power and scope of these purchases have the potential to transform supply chains even for non-public entities. Previous estimates of the scale of public procurement suggest that 8–25% of the gross domestic product of Organisation for Economic Cooperation and Development (OECD) countries and 16% of European Union (EU) GDP are attributable to government purchases of goods or services (Brammer & Walker, 2011). Green public procurement is a "demand side" policy that functions by creating the demand for sustainable produced products (Cheng *et al*., 2018). Achievement of this target could have direct positive impacts on nature and NCP and therefore on SDGs 6, 14, and 15. Leadership and senior manager support for sustainable green procurement and its inclusion in planning, strategies and goal setting is a major factor in its implementation. Similarly, if government policy and legislation support sustainable procurement, public sector organizations are more likely to implement it. Challenges for sustainable public procurement include the voluntary nature of most policies and practices and competing budgetary constraints (Brammer & Walker, 2011). Sustainable public procurement is still relatively nascent, and research has focused more on implementation than effectiveness, so the scope of potential impacts remains unknown (Cheng *et al*., 2018).

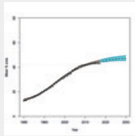
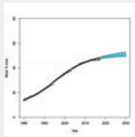
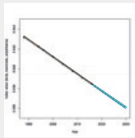
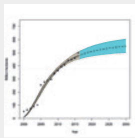
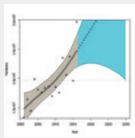
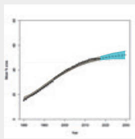
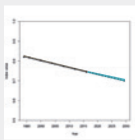
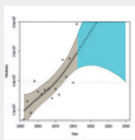
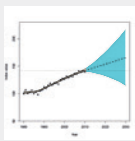
Target 12.8 is similar in aims to Aichi Target 1, on raising awareness of biodiversity and the steps needed to conserve and use it sustainably. As discussed in section 3.2, progress on this issue has so far been insufficient, but is increasing, although these findings largely related to awareness of biodiversity values **(Table 3.3)**. There is currently little evidence as to progress on public awareness and information on sustainable development, suggesting it has not yet had large-scale general uptake. SDG 4 is also relevant and is discussed above under the GQL cluster.

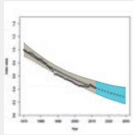
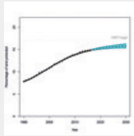
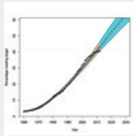
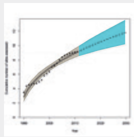
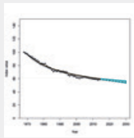
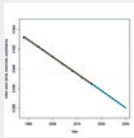
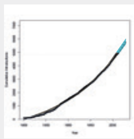
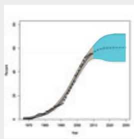
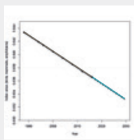
Table 3 7 **Trends of indicators extrapolated to 2030 to assess progress towards Sustainable Development Goals 6, 14 and 15 and their targets that are most closely related to nature and its contributions to people.**

Targets listed in red had no indicators suitable for extrapolation. Larger format versions of the thumbnail graphs, which include y-axis labels and background information on each indicator, are provided in Table S3.6.

SDG	Target	Indicator name	Alignment	Projected trend (2010-2030)	Graph
CLEAN WATER & SANITATION	**6.3** By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally				
	6.4 By 2030, substantially increase water-use across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity				
	6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate				
	6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	Percentage of freshwater Key Biodiversity Areas covered by protected areas*	High	Significant increase	
		Wetland Extent Trends Index	Medium	Significant decrease	
LIFE BELOW WATER	**14.1** By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution	Red List Index (impacts of pollution)	Low	Significant decrease	
	14.2 By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans				
	14.3 Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels				
	14.4 By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics	Proportion of fish stocks in safe biological limits*	High	Non-significant decrease	

SDG	Target	Indicator name	Alignment	Projected trend (2010-2030)	Graph
		Marine Stewardship Council engaged fisheries (tonnes)	High	Significant increase	
		Red List Index (impacts of fisheries)	Medium	Significant decrease	
	14.5 By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information	Percentage of marine and coastal areas covered by protected areas*	High	Significant increase	
		Percentage of marine Key Biodiversity Areas covered by protected areas	High	Significant increase	
	14.6 By 2020, prohibit certain forms of fisheries subsidies which contribute to overcapacity and overfishing, eliminate subsidies that contribute to illegal, unreported and unregulated fishing and refrain from introducing new such subsidies, recognizing that appropriate and effective special and differential treatment for developing and least developed countries should be an integral part of the World Trade Organization fisheries subsidies negotiation.				
	14.7 By 2030, increase the economic benefits to small island developing States and least developed countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture and tourism				
LIFE ON LAND	**15.1** By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements	Percentage of terrestrial areas covered by protected areas	High	Significant increase	
		Percentage of terrestrial ecoregions covered by protected areas	Medium	Significant increase	
		Number of protected area management effectiveness assessments	Low	Significant increase	

SDG	Target	Indicator name	Alignment	Projected trend (2010-2030)	Graph
		Percentage of freshwater Key Biodiversity Areas covered by protected areas*	High	Significant increase	
		Percentage of terrestrial Key Biodiversity Areas covered by protected areas*	High	Significant increase	
		Red List Index (impacts of utilization)	High	Significant decrease	
	15.2 By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally	Area of forest under sustainable management: total FSC and PEFC forest management certification (million ha)	High	Significant increase	
		Area of tree cover loss (ha)	High	Significant increase	
	15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world				
	15.4 By 2030, ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development	Percentage of mountain Key Biodiversity Areas covered by protected areas*	High	Significant increase	
	15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species	Red List Index*	High	Significant decrease	
		Area of tree cover loss (ha)	Medium	Significant increase	
		Climatic Impact Index for Birds	Medium	Significant increase	

SDG	Target	Indicator name	Alignment	Projected trend (2010-2030)	Graph
		Living Planet Index	High	Significant decrease	
		Percentage of terrestrial areas covered by protected areas	High	Significant increase	
		Percentage of terrestrial ecoregions covered by protected areas	Medium	Significant increase	
		Number of protected area management effectiveness assessments	Low	Significant increase	
		Wild Bird Index (habitat specialists)	High	Significant decrease	
	15.6 Promote fair and equitable sharing of the benefits arising from the utilization of genetic resources and promote appropriate access to such resources, as internationally agreed				
	15.7 Take urgent action to end poaching and trafficking	Red List Index (impacts of utilization)	Medium	Significant decrease	
	15.8 By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species	Number of invasive alien species introductions	High	Significant increase	
		Percentage of countries with invasive alien species legislation	High	No significant change	
		Red List Index (impacts of invasive alien species)	High	Significant decrease	

SDG	Target	Indicator name	Alignment	Projected trend (2010-2030)	Graph
	15.9 By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts				
	15.a Mobilize and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems				
	15.b Mobilize significant resources from all sources and at all levels to finance sustainable forest management and provide adequate incentives to developing countries to advance such management, including for conservation and reforestation				

Selected Sustainable Development Goals	Selected targets (abbreviated)	Recent status and trends in aspects of nature and nature's contributions to people that support progress towards target *		Uncertain relationship
		Poor/Declining support	Partial support	
No poverty	1.1 Eradicate extreme poverty			U
	1.2 Halve the proportion of people in poverty			U
	1.4 Ensure that all have equal rights to economic resources			
	1.5 Build the resilience of the poor			
Zero hunger	2.1 End hunger and ensure access to food all year round			
	2.3 Double productivity and incomes of small-scale food producers			
	2.4 Ensure sustainable food production systems			
	2.5 Maintain genetic diversity of cultivated plants and farmed animals			
Good health and well-being	3.2 End preventable deaths of newborns and children			U
	3.3 End AIDS, tuberculosis, malaria and neglected tropical diseases			U
	3.4 Reduce premature mortality from non-communicable diseases	Unknown		
	3.9 Reduce deaths and illnesses from pollution	Unknown		
Clean water and sanitation	6.3 Improve water quality			
	6.4 Increase water use and ensure sustainable withdrawals			
	6.5 Implement integrated water resource management			
	6.6 Protect and restore water-related ecosystems			
Sustainable cities and communities	11.3 Enhance inclusive and sustainable urbanization			
	11.4 Protect and safeguard cultural and natural heritage			
	11.5 Reduce deaths and the number of people affected by disasters			
	11.6 Reduce the adverse environmental impact of cities			
	11.7 Provide universal access to green and public spaces			
Climate action	13.1 Strengthen resilience to climate-related hazards			
	13.2 Integrate climate change into policies, strategies and planning			
	13.3 Improve education and capacity on mitigation and adaptation	Unknown		
	13a Mobilize US$100 billion/year for mitigation by developing countries	Unknown		
	13b Raise capacity for climate change planning and management	Unknown		
Life below water	14.1 Prevent and reduce marine pollution			
	14.2 Sustainably manage and protect marine and coastal ecosystems			
	14.3 Minimize and address ocean acidification			
	14.4 Regulate harvesting and end overfishing			
	14.5 Conserve at least 10 per cent of coastal and marine areas			
	14.6 Prohibit subsidies contributing to overfishing			
	14.7 Increase economic benefits from sustainable use of marine resources			

Life on land	15.1 Ensure conservation of terrestrial and freshwater ecosystems			
	15.2 Sustainably manage and restore degraded forests and halt deforestation			
	15.3 Combat desertification and restore degraded land			
	15.4 Conserve mountain ecosystems			
	15.5 Reduce degradation of natural habitats and prevent extinctions			
	15.6 Promote fair sharing of benefits from use of genetic resources			
	15.7 End poaching and trafficking			
	15.8 Prevent introduction and reduce impact of invasive alien species			
	15.9 Integrate biodiversity values into planning and poverty reduction			
	15a Increase financial resources to conserve and sustainably use biodiversity			
	15b Mobilize resources for sustainable forest management			

* There were no targets that were scored as good/positive status and trends

Figure 3 13 **Summary of recent status of, and trends in, aspects of nature and nature's contributions to people that support progress towards achieving selected targets of the Sustainable Development Goals.**

Selected targets are those where current evidence and target wording enable assessment of the consequences for target achievement of trends in nature and nature's contribution to people. Chapter 3 section 3.3 provides a goal-level assessment of the evidence of links between nature and all Sustainable Development Goals. Scores for targets are based on systematic assessments of the literature and quantitative analysis of indicators where possible. None of the targets scored 'Full support' (that is, good status or substantial positive trends at a global scale); consequently, it was not included in the table. 'Partial support': the overall global status and trends are good or positive but insubstantial or insufficient, or there may be substantial positive trends for some relevant aspects but negative trends for others, or the trends are positive in some geographic regions but negative in others; 'Poor/Declining support': poor status or substantial negative trends at a global scale; "Uncertain relationship": the relationship between nature and/or nature's contributions to people and achieving the target is uncertain; "Unknown": insufficient information to score the status and trends.

3.3.3 The Sustainable Development Goals and Indigenous Peoples and Local Communities

In this section, we review the role of IPLCs in efforts to achieve the SDGs, their contributions to progress to date, and the implications of achieving the SDGs to IPLCs. We focus primarily on the positive contributions that IPLCs make to achieve SDGs and their targets, but recognize that there are exceptions, some related to differing worldviews, and note some of these in the text. IPLCs have participated in meetings held under CBD and other international initiatives such as UNPFII, EMRIPS and the special rapporteur on Indigenous Peoples' rights. However, overall, Indigenous Peoples' participation at the UN level has been smaller than desirable. National dialogue on the Sustainable Development Goals (SDGs) between Indigenous Peoples and governments has also very limited in most countries (AIPP *et al*., 2015). Indigenous Peoples are mentioned only six times in the SDGs, and only in two targets (2.3, 4.5), which has been seen as a major disappointment for IPLCs (AIPP *et al*., 2015), UN Environment, 2015), although the lack of mentions elsewhere does not limit application of the broader goals and targets to their specific contexts. While a lot of the themes promoted and advocated by Indigenous Peoples in recent years have been included in the 2030 Agenda, the SDGs lack attention to issues such as the importance of free, prior and informed consent, and potential conflicts between the economic growth goals of the agenda and the environmental and social goals. an opportunity to use the SDGs to continue advances (AIPP *et al*., 2015). Weak participation in setting the goals hampers IPLCs ability to monitor and assess progress.

SDG 1: End poverty in all its forms everywhere

Indigenous Peoples are accounted as the poorest of the world's poor (Hall & Patrinos, 2012; Macdonald, 2012). Moreover, poverty is higher in rural remote areas (Ahmed *et al*., 2007; Sunderlin *et al*., 2005) and areas of importance for biodiversity conservation (Fisher & Christopher, 2007), where most IPLCs live. Nevertheless, IPLCs have a threefold contribution to poverty eradication. First, IPLCs are the main actors in the so-called win-win initiatives (or triple benefit; Brockington & Duffy, 2011) aimed at biodiversity conservation and climate mitigation while improving income level (e.g., Adhikari *et al*., 2004; Ahenkan & Boon, 2010; Brown *et al*., 2011; Campos-Silva & Peres, 2016; Chirenje, 2017; Dulal *et al*., 2012; El Bagouri, 2007; Roe, 2008). Second, IPLCs traditional institutions (e.g., taboos; Cinner *et al*., 2009), ILK and management practices (e.g., diversification) help mitigate the effects of poverty and vulnerabilities (Aryal *et al*., 2014) and to adapt to natural disasters and global changes (Ingty, 2017; Parraguez-Vergara *et al*., 2016). Third, interventions among IPLCs have contributed to the debate on whether poverty definitions based on monetary indicators are adequate (Fukuda-Parr, 2016). IPLCs often have different understandings of what poverty or wealth are (Chambers, 2005), rely on non-monetary sources of wild natural resources (Angelsen *et al*., 2014; Ehara *et al*., 2016; Robinson, 2016), and face multiple stressors (Gratzer & Keeton, 2017), or multidimensional poverty. Given that conservation and development interventions occasionally coincide with the loss of access to land and resources (e.g., Asquith *et al*., 2002), income (e.g., L'Roe & Naughton-Treves, 2014), and traditional livelihoods and culture (Mbaiwa *et al*., 2008) alternative approaches to monetary assessments of poverty have been devised for understanding and guiding policymaking (Bridgewater *et al*., 2015) and environmental policy frameworks (e.g., in REDD+ safeguards; Arhin, 2014) addressed to IPLCs. As remote rural inhabitants rely substantially on natural resources, increased access to monetary income may affect IPLC livelihoods, while also impacting biodiversity in multiple ways (Godoy *et al*., 2005), not necessarily taking pressure off natural resources (Angelsen *et al*., 2014). Moreover, the evidence regarding integrated conservation and poverty alleviation initiatives has been mixed and sometimes poorly quantified (Charnley & Poe, 2007; Romero-Brito *et al*., 2016). Restricting IPLCs' rights on forest products harvest and trade has precluded opportunities for income generation (e.g., Mbaiwa *et al*., 2008; Scheba & Mustalahti, 2015), or lowered cash income (e.g., Katikiro, 2016). Government and non-government development projects have frequently neglected IPLCs' rights and knowledge and have not adequately addressed asymmetric relations and inequities in their access to economic and political opportunities (Reyes-Garcia *et al*., 2010). Government-led poverty-alleviation programs are not necessarily adapted to IPLCs, sometimes being culturally inaccessible to indigenous families (Zavaleta *et al*., 2017).

SDG2: Zero Hunger

IPLCs have developed a variety of systems to achieve local food security through sustainable use of the environment. For example, research shows that traditional farming systems that exploit biodiversification, soil and water management have helped IPLCs to achieve food security through sustainable agricultural production (Altieri & Nicholls, 2017; Bjornlund & Bjornlund, 2010). Similarly, sustainable forest management, agroforestry, wild edible plant collection (Appiah & Pappinen, 2010; Boscolo *et al*., 2010; Ciftcioglu, 2015; Takahashi & Liang, 2016) and small-scale fisheries (Ali *et al*., 2017) have also played a vital role in IPLCs' food security. However, malnutrition and under nourishment among children under five years old is major problem among some IPLCs, particularly after they lose access to their lands and traditional livelihoods (Anticona & Sebastian, 2014; Babatunde, 2011; Dutta & Pant, 2003; Ferreira *et al*., 2012; Gracey, 2007). Moreover, dietary transitions affecting IPLCs are leading to increasing rates of overweight, obesity and associated chronic diseases, known as "hidden hunger" (Crittenden & Schnorr, 2017; Ganry *et al*., 2011; Kuhnlein *et al*., 2006, 2009; Popkin, 2004). Scientists now recognize that many food production systems developed by IPLCs could contribute to sustainable food production (Altieri & Nicholls, 2017; Barrios *et al*., 2015; Campos-Silva & Peres, 2016; Kahane *et al*., 2013; Pauli et. al 2016; Winowiecki et. al. 2014). However, it is also acknowledged that the success of programs integrating insights from those systems remains dependent on rights and access allocation, corruption, lack of local financial, intellectual and innovative capacity and centralized governance (Ferrol-Schulte *et al*., 2013), for which policies to fight hunger need addressing not only technical measures, but also tackling power asymmetries that reduce access to land and other resources for IPLCs (Francescon, 2006; Beckh *et al*., 2015) or raising investment in capital and organizational infrastructure (Godfray *et al*., 2010).

SDG 3: Ensure healthy lives and promote well-being for all at all ages

While most contemporary peoples have plural medical systems, traditional medicine continues to play an important role among IPLCs (Cartaxo *et al*., 2010; Chekole, 2017; Cox, 2004; Moura-Costa *et al*., 2012; Padalia *et al*., 2015; Paniagua-Zambrana *et al*., 2015; Tolossa *et al*., 2013). Limited access to other healthcare systems makes traditional medicine the only treatment option in certain communities (Paniagua-Zambrana *et al*., 2015; Tolossa *et al*., 2013); however, traditional medicine can be the preferred treatment option even when other healthcare systems are accessible (Padalia *et al*., 2015). Medicinal ILK has contributed to the discovery of active principles for drug development to treat non-communicable and infectious diseases, including AIDS, neglected tropical diseases, hepatitis, and water-borne diseases (Cartaxo *et al*., 2010; Johnson *et al*., 2008; Moura-Costa *et al*., 2012; Padalia *et al*., 2015; Tolossa *et al*., 2013; Rullas *et al*., 2004). This use, however, has often neglected IPLCs' contributions, giving raise to conflicts over unfair appropriation of ILK (Nelliyat, 2017). Research has shown higher rates of mortality and morbidity among Indigenous Peoples than among their non-indigenous counterparts (Anderson *et al*., 2016; Coimbra *et al*., 2013; Hernandez *et al*., 2017; Hurtado *et al*., 2005). Nutritional transitions have also resulted in a high prevalence and incidence of obesity, diabetes, and poor nutrition among many IPLCs (e.g., Corsi *et al*., 2008; McDermott *et al*., 2009; Port Lourenco *et al*., 2008; Rosinger *et al*., 2013) as well as high rates of alcohol use and tobacco smoking (Kirmayer *et al*., 2000; Natera *et al*., 2002; Wolsko *et al*., 2007). Given IPLCs' direct dependence on the environment to cover their material (e.g., water, food, shelter and medicines) and cultural needs (e.g., spiritual beliefs and worldviews), environmental changes (e.g., climate change, chemical contamination, land use changes) threaten to jeopardize the achievement of SDG3 for IPLCs (Anderson *et al*., 2015; Aparicio-Effen *et al*., 2016; Bradford *et al*., 2016; Dudley *et al*., 2015; Genthe *et al*., 2013). ILK can aid in the development of local strategies to cope with environmental factors that might put at risk IPLCs' health (Negi *et al*., 2017; Rahman & Alam, 2016), and there exists a handful of community-based interventions aimed at controlling infectious diseases in a sustainable, environmentally friendly way (Andersson *et al*., 2015; Arunachalam *et al*., 2012; Ledogar *et al*., 2017). Some researchers argue for the need to create new indicators of indigenous health that are socially and culturally sensitive and that adopt a more holistic and integrated approach, capturing IPLC definitions of health and well-being (Malkina-Pykh & Pykh, 2008; McMhom, 2002; Zorondo-Rodriguez *et al*., 2014) and addressing the causes of inequalities (Hernandez *et al*., 2017; WHO, 2013).

SDG 6: Clean Water and Sanitation

There is well established evidence that IPLCs have developed complex customary institutions for governing and managing freshwater resources in sustainable ways (e.g., Boelens, 2014; Strauch *et al*., 2016; Tharakan, 2015; Weir *et al*., 2013). Many studies have shown the strong cultural and spiritual ties between IPLCs and freshwater bodies (e.g., lakes, rivers and lagoons), which are deeply rooted in cultural beliefs and social practices and are thus at the basis of IPLC customary institutions for water management (e.g., Anderson *et al*., 2013; Dallmann *et al*., 2013; Jaravani *et al*., 2017; McGregor 2012). ILK-based water management systems are diverse, and include time-honored practices such as rainwater harvesting (Oweis, 2014; Widiyanti & Dittmann, 2014), small-scale sand dams (Lasage *et al*., 2008, 2015), water tanks (Ariza-Montobbio *et al*., 2007; Reyes-García *et al*., 2011), traditional water purification methods (Mwabi *et al*., 2013; Opare, 2017), forestry-based groundwater recharge (Camacho *et al*., 2016; Everard *et al*., 2018; Strauch *et al*., 2016), and complex systems of river zonation (e.g., Tagal System in Malaysia; AIPP, 2015; Halim *et al*., 2013). Additionally, several water-smart agricultural practices have been deemed effective at simultaneously ensuring water availability and conservation of biodiversity (Hughey & Booth, 2012; Lasing, 2006; Reyes-García *et al*., 2011). The strong cultural connections that IPLCs maintain with their freshwater bodies have allowed them to closely monitor water availability and quality (Alessa *et al*., 2008; Bradford *et al*., 2017; Sardarli, 2013). There is well established evidence that water insecurity disproportionately impacts IPLCs (Medeiros *et al*., 2017; Lam *et al*., 2017), resulting in multiple adverse health, economic and sociocultural burdens (e.g., Daley *et al*., 2015; Henessy & Bressler, 2016; Sarkar *et al*., 2015). Research shows that IPLCs have systematically lower access to clean water supplies than other segments of the population (Baillie *et al*., 2004; McGinnis & Davis, 2001; Ring & Brown, 2002), leading to high prevalence of several infectious diseases (Anuar *et al*., 2016; Han *et al*., 2016; Stigler-Granados *et al*., 2014). Moreover, environmental pollution (Bradford *et al*., 2017; Dudarev *et al*., 2013) and climate change (Dussias, 2009; Ford *et al*., 2014; Nakashima *et al*., 2012) exacerbate ongoing threats to the water supplies of IPLCs. IPLCs are also some of the most vulnerable groups to the impact of large-scale water resource development projects (Finn & Jackson, 2011; King & Brown, 2010), including dams and irrigations plans (Dell'Angelo *et al*., 2017; Winemiller *et al*., 2016). IPLCs have often been excluded from water decision-making bodies (Finn & Jackson, 2011; Hanrahan, 2017; Weir, 2010), as narrow conceptualizations of IPLCs water rights limit their ability to sustainably manage water resources according to traditional responsibilities (Durette, 2010; Tan & Jackson, 2013). Low participation of IPLCs in water management bodies has often fueled water conflicts and disagreement over the most culturally-appropriate policy options to ensure availability and sustainable management of water (Jiménez *et al*., 2015; Trawick, 2003). If interventions aimed at improving the role of indigenous water management systems are to be effective, water resource planners need to consider not only technical but also sociocultural factors (Dobbs *et al*., 2016; Jaravani *et al*., 2016; Pahl-Wostl *et al*., 2007; Reyes-García *et al*., 2011), including greater respect towards ILK and IPLC cultural values (Henwood *et al*., 2016; Maclean & The Bana Yarralji Bubu Inc. 2015; Tipa, 2009).

SDG 11: Sustainable cities and communities

It is increasingly acknowledged that IPLCs can contribute to enhance urban sustainability in aspects such as efficient water and energy consumption, reducing waste production and improving its disposal, reducing urban carbon footprints, and making urban agriculture more sustainable (e.g., Cosmi *et al*., 2016; Barthel *et al*., 2010; Langemeyer *et al*., 2017; Mihelcic *et al*., 2007; Schoor *et al*., 2015). IPLCs can also contribute to social-ecological resilience and to a sustained flow of ecosystem services in urban contexts under change (Andersson & Barthel, 2016; Hurlimann *et al*., 2014), as shown in examples from European cities during World Wars I and II (Barthel *et al*., 2015) and Havana, Cuba, after the end of the Soviet Union (Altieri *et al*., 1999). IPLCs can make cities safer by improving disaster risk detection and management, for which scholars have defended the importance of integrating ILK into risk assessment and management programs (Arriagada-Sickinger *et al*., 2016; Zweig, 2017). IPLCs and ILK are increasingly being valued in sustainable urban planning and design (Bunting *et al*., 2010; Young *et al*., 2017), but there is a further need to continue to do so, for which efficient methods are emerging (Kyttä *et al*., 2013, 2016; Samuelsson *et al*., 2018). Yet, researchers have also argued that IPLCs alone are not sufficient to create critical urban resilience, underscoring the need for functioning institutions to support IPLCs (Walters, 2015).

SDG 12: Responsible consumption and production

The existing body of academic research on IPLCs and responsible production and consumption is illuminating on three issues that not only affect IPLCs but are also obstacles for sustainable development. First, there is much heterogeneity between people with regards to drivers and consequences of resource use expansion linked to unsustainable production and consumption (Pichler *et al*., 2017). Through their low degree of involvement with mass production and consumption, IPLCs are not a driving force of the global environmental change from which they nevertheless disproportionally suffer (Chance and Andreeva, 1995; Martinez-Alier, 2014; Smith and Rhiney, 2016; Tsosie, 2007). Second, power disparities play a critical role in the appropriation of natural resources, including via the appropriation of ILK. As the resource frontier is continuously expanded for economic growth and increased production and consumption, encroachment on IPLCs' land has become widespread (e.g., Finer *et al*., 2008; Pichler, 2013), commonly threatening livelihoods (Bunker, 1984; Gerber, 2011; Larsen *et al*., 2014; Mingorría *et al*., 2014). In this economic model, the power of IPLCs to determine resource use is severely restricted (Benda-Beckmann & Benda-Beckmann, 2010, Devine & Ojeda, 2017; Li, 2001, 2010; Watts and Vidal, 2017). Notwithstanding this, the appropriation of ILK is considered pivotal in attaining more sustainable management of resources (e.g., Fearnside, 1999; Gadgil *et al*., 1993; Johannes *et al*., 2000; Véron, 2001). Published research has focused very strongly on integrating ILK into the existing capitalist system of production and consumption (Donovan and Puri, 2004; Ilori *et al*., 1997; Kahane *et al*., 2013; Sarkar, 2013; Usher, 2000) with its reliance on growth through the appropriation of resources and labour (Moore, 2015). Integrating ILK into production and consumption may endanger any sustainability benefits (Nadasdy, 1999b). Third, despite the inherent unsustainability of the current resource use trajectory, existing tools for sustainable resource management typically propose the integration of IPLC claims (Fernandez-Gimenez *et al*., 2006; O'Faircheallaigh, 2007), rather than interpreting the (often non-monetary) preferences of IPLCs (Avcı *et al*., 2010; Dongoske *et al*., 2015; Martinez-Alier, 2009) in terms of possible alternative resource use futures (White, 2006). To achieve sustainable production and consumption, greater consideration is needed of alternative visions of what it means to prosper and to live well, rather than in material abundance (Kothari *et al*., 2014; Radcliffe, 2012; Zimmerer, 2015).

SDG 13: Climate Action. Combat climate change and its impacts

It is well established that IPLCs have contributed to mitigation of climate change effects (Campbell, 2011; Gabay *et al*., 2017; Lunga & Musarurwa, 2016), partly because of their low contribution to GHG emissions (Heckbert *et al*., 2012; Russell-Smith *et al*., 2013). Agreement is also growing that ILK can be an alternative source of knowledge in efforts to mitigate and adapt to climate change (Altieri & Nicholls, 2017; Chanza & De Wit, 2016; Eicken, 2010; Magni, 2017; Pearce *et al*., 2015). It is also well acknowledged that IPLCs are among the groups most affected by the impacts of climate change**,** including effects of unexpected extreme rainfall events (Baird *et al*., 2014; Joshi *et al*., 2013), floods (Cai *et al*., 2017), droughts (Kalanda-Joshua *et al*., 2011; Swe *et al*., 2015), pasture disappearance (He & Richards, 2015; Wu *et al*., 2015), extinction of medicinal plants (Klein *et al*., 2014; Mapfumo *et al*., 2016), changes in animal behaviour patterns (Pringle & Conway, 2012), and the spread of pests and invasive alien species (Shijin & Dahe, 2015; Shukla *et al*., 2016). While in the past, ILK had allowed IPLCs to understand weather variability and change, ILK might now be less accurate as weather becomes increasingly unpredictable (Cai *et al*., 2017; Konchar *et al*., 2015). The failure of ILK to detect, interpret and respond to change generates a feeling of insecurity and defenselessness that undermines IPLC resilience and exacerbates their vulnerability (Mercer & Perales, 2010; Simelton *et al*., 2013). The potential of combining ILK and scientific knowledge to design successful climate adaptation policies is increasingly acknowledged (Alessa *et al*., 2016; Altieri and Nicholls, 2017; Austin *et al*., 2017; Boillat & Berkes, 2013; Hiwasaki *et al*., 2014; Ingty, 2017; Kasali, 2011; Mantyka-Pringle *et al*., 2017), although there are few efforts to make IPLCs aware of the scientific approaches being promoted to combat climate change impacts (Fernández-Llamazares *et al*., 2015; Inamara & Thomas, 2017; Shukla *et al*., 2016), and examples of initiatives aiming to integrate ILK into climate policies are still rare (Seijo *et al*., 2105). Increasing the adoption of climate-smart technologies among IPLCs might contribute to strengthen their adaptive capacity (Scherr *et al*., 2012).

SDG 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development

IPLCs have long history of interacting with the oceans and sustainably managing coastal and marine resources (Cordell, 1989; Johannes, 1978; Lepofsky & Caldwell, 2013; Lotze & Milewski, 2004; Spanier *et al*., 2015; Thornton & Mamontova, 2017). IPLCs also have a deep knowledge of marine ecology (McGreer & Frid, 2017; Salomon *et al*., 2007; Savo *et al*., 2017) that can help sustainably manage marine ecosystems, including coral reefs and mangroves (Cinner *et al*., 2006; Datta *et al*., 2012; Thaman *et al*., 2017). However, traditional marine management regimes can also result in intense resources exploitation (e.g., Andreu-Cazenave *et al*., 2017; Islam & Haque, 2004; Ratner, 2006), for which researchers have warned against the uncritical use of ILK (Turner *et al*., 2013; Turvey *et al*., 2010). The continued degradation of marine ecosystems affects the many IPLCs who are dependent on them, affecting food security (de Lara & Corral, 2017; McGreer & Frid, 2017; Robards & Greenberg, 2007; Watts *et al*., 2017) and social and spiritual integrity (McCarthy *et al*., 2014). Moreover, IPLCs also face important social restrictions regarding marine resources use, including fishing and tenure right restrictions (Joyce & Satterfield, 2010; Thornton &

Mamontova, 2017) and coastal lands dispossession by outside interests (e.g., governments, tourist operators) (Bavinck *et al*., 2017; Hill, 2017). While including IPLCs in managing marine resources can help sustainably managing marine ecosystems (Jupiter *et al*., 2014b), this potential is not always recognized (Johnson *et al*., 2016; Jones *et al*., 2017). Moreover, in many areas traditional fishing techniques have been made illegal (Deur *et al*., 2015; Jones *et al*., 2017; Langdon, 2007; von der Porten *et al*., 2016).

SDG 15: Life on land

With an estimated 28% of the world's land surface held by IPLCs (Garnett *et al*., 2018) and 80% of biodiversity found there (FAO, 2017), IPLCs play a substantial role in governing and managing forests, land, and biodiversity. The often long-lasting relationship between IPLCs and terrestrial ecosystems has led to a co-evolution of social and ecological components that has enhanced adaptive capacity, resilience and sustainability (Berkes *et al*., 2000; Folke, 2006; MacLean *et al*., 2013; Pascua *et al*., 2017). IPLCs contribute to the maintenance and enhancement of land-based ecosystems through management practices that focus on ecological processes (Herrmann & Torri, 2009; see also 2.2.4), multiple use (Toledo *et al*., 2003), agroforestry (Suyanto *et al*., 2005), sustainable logging and hunting (Roopsind *et al*., 2017), fire management (Mistry *et al*., 2016), protection and management of culturally significant trees (Genin & Simenel, 2011; Stara *et al*., 2015), and long-term monitoring (Long & Zhou, 2001; Olivero *et al*., 2016). Giving land titles to IPLCs tends to protect forests from large-scale conversion into other land uses (Blackman *et al*., 2017; Chhatre *et al*., 2012; Nepstad *et al*., 2006) and forests that have cultural and religious significance for IPLCs are usually more diverse, denser and harbour larger and older trees than non-sacred forests (Aerts *et al*., 2016; Borona, 2014; Frascaroli *et al*., 2016; Ormsby, 2013; Rao *et al*., 2011). IPLCs directly benefit from biodiversity, for example through the use of wild plants in diet and medicinal purposes (Singh *et al*., 2014). Biodiversity can have a spiritual importance to IPLCs (Torri & Herrmann, 2011). Biodiversity also makes cultural landscapes and agroecosystems more resilient to climate change (Altieri & Nicholls, 2017; Ingty, 2017). Furthermore, non-extractive uses of biodiversity can provide additional income to IPLCs through carbon offsetting (Renwick *et al*., 2014), ecotourism (Gonzalez *et al*., 2008; Sakata & Prideaux, 2013) and intellectual property rights on biodiversity use (Efferth *et al*., 2016). Yet the equitable sharing of these benefits remains a challenge in practice (De Jonge, 2011; Suiseeya, 2014). IPLCs benefit from ecosystem services provided by resilient lands (Sigwela *et al*., 2017) and are particularity vulnerable to land degradation (Ellis-Jones, 1999). The largest body of literature addresses the participation of IPLCs in combating land degradation in relation with externally supported projects and the need to establish effective participation and knowledge co-production schemes (Oba *et al*., 2008; Raymond *et al*., 2010b; Reed *et al*., 2013; Sedzimir, 2011). While there is relatively little literature on how IPLCs can contribute to combat desertification, the existing one shows that IPLCs have also contributed to fight desertification and soil erosion through indigenous initiatives, some of them rooted in a long-term relation with their environment. This includes plant selection for resistance to drought (Gaur & Gaur, 2004), keeping spiritually relevant patches of forest to halt soil erosion (Yuan & Liu, 2009), the construction and maintenance of traditional irrigation systems (Ashraf *et al*., 2016; Ostrom, 1990), traditional knowledge on soil types and conditions (Barrera-Bassols *et al*., 2006) and terrace construction (Boillat *et al*., 2004). IPLCs can play a key role in monitoring land degradation and soil conditions (Forsyth, 1996; Roba & Oba, 2009) and in land rehabilitation (Yirdaw *et al*., 2017).

3.4 PROGRESS TOWARDS GOALS AND TARGETS OF OTHER GLOBAL AGREEMENTS RELATED TO NATURE AND NATURE'S CONTRIBUTIONS TO PEOPLE

There are more than 150 multilateral environmental agreements related to biodiversity, but six are global in scope and pursue biodiversity conservation as a core objective (Gomar *et al*., 2014). These comprise one framework convention—the 1992 Convention on Biological Diversity (CBD)—and five focused agreements: (1) the 1971 Convention on Wetlands of International Importance Especially as Waterfowl Habitat (the Ramsar Convention on Wetlands); (2) the 1972 Convention Concerning the Protection of the World Cultural and Natural Heritage (WHC); (3) the 1973 Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES); (4) the 1979 Convention on the Conservation of Migratory Species of Wild Animals (CMS); and (5) the 2001 International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA; S3.10). In this section, we review progress towards the goals of the first four of these Conventions, plus the International Plant Protection Convention (IPPC) and the United Nations Convention to Combat Desertification (UNCCD), as the implementation of both of these has a significant impact on biodiversity and livelihoods. Given that the ITPGRFA has not yet adopted a strategic plan with specified objectives, we do not assess progress, but address this Convention in section S3.10. We also address the United Nations Convention on the Law of the Sea (UNCLOS; Articles 61-66; **Box 3.1**), given that all of the others focus solely on the terrestrial realm **(Table 3.8)**, and two polar conventions, given the global consequences of conservation of these two regions: the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) and the Arctic Council's Conservation of Arctic Flora and Fauna (CAFF, **Box 3.2**). The means by which the CBD coordinates efforts with these MEAs is covered in section S3.9.

Table 3.8 summarizes a high-level assessment of the literature on progress towards the goals and strategic objectives of CMS, CITES, Ramsar Convention, UNCCD, WHC, and IPPC. A more rigorous quantitative analysis of indicators for each of the detailed underlying targets, like that employed for the Aichi Biodiversity Targets in section 3.2, is needed to validate these assessments, but is beyond the scope of this chapter.

Table 3 8 **Progress towards achieving the goals of other global agreements related to nature and nature's contributions to people, based on a synthesis of the literature and available information.**

Progress towards goals is scored as Good (substantial positive trends at a global scale relating to most aspects of the element), Moderate (the overall global trend is positive, but insubstantial or insufficient, or there may be substantial positive trends for some aspects of the goal, but little or no progress for others, or the trends are positive in some geographic regions but not in others), Poor (little or no progress towards goal, or movement away from goal; while there may be local/national or case-specific successes and positive trends for some aspects, the overall global trend shows little or negative progress), or Unknown '?' (insufficient information to score progress).

Convention	Goals	Progress
CMS	**Goal 1:** Address the underlying causes of decline of migratory species by mainstreaming relevant conservation and sustainable use priorities across government and society	
	Goal 2: Reduce the direct pressures on migratory species and their habitats	
	Goal 3: Improve the conservation status of migratory species and the ecological connectivity and resilience of their habitats	
	Goal 4: Enhance the benefits to all from the favourable conservation status of migratory species	?
	Goal 5: Enhance implementation through participatory planning, knowledge management and capacity-building	

Convention	Goals	Progress
CITES	**Goal 1:** Ensure compliance with and implementation and enforcement of the Convention.	
	Goal 2: Secure the necessary financial resources and means for the operation and implementation of the Convention.	
	Goal 3: Contribute to significantly reducing the rate of biodiversity loss by ensuring that CITES and other multilateral instruments and processes are coherent and mutually supportive.	
RAMSAR	**Goal 1:** Addressing the drivers of wetland loss and degradation	
	Goal 2: Effectively conserving and managing the Ramsar site network	
	Goal 3: Wisely using all wetlands	
	Goal 4: Enhancing implementation	
UNCCD	**Goal 1:** To improve the living conditions of affected populations	
	Goal 2: To improve the condition of affected ecosystems	
	Goal 3: To generate global benefits through effective implementation of the UNCCD	
	Goal 4: To mobilize resources to support implementation of the Convention through building effective partnerships between national and international actors	
WHC	**Objective 1:** Strengthen the Credibility of the World Heritage List, as a representative and geographically balanced testimony of cultural and natural properties of outstanding universal value	
	Objective 2: Ensure the effective Conservation of World Heritage properties	
	Objective 3: Promote the development of effective capacity-building measures, including assistance for preparing the nomination of properties to the World Heritage List, for the understanding and implementation of the World Heritage Convention and related instruments	
	Objective 4: Increase public awareness, involvement and support for World Heritage through Communication	
	Objective 5: Enhance the role of Communities in the implementation of the World Heritage Convention	
IPPC	**Strategic objective A:** To protect sustainable agriculture and enhance global food security through the prevention of pest spread;	
	Strategic objective B: To protect the environment, forests and biodiversity from plant pests	
	Strategic objective C: To facilitate economic and trade development through the promotion of harmonized scientifically based phytosanitary measures	
	Strategic objective D: To develop phytosanitary capacity for members to accomplish objectives A, B and C	

3.4.1 The Convention on the Conservation of Migratory Species of Wild Animals

The CMS (or 'Bonn Convention') is an intergovernmental treaty aimed at conserving terrestrial, marine and avian migratory species throughout their range (CMS, 2017). Signed in 1979 and entering into force in 1983, the Convention is currently ratified by 124 Parties. CMS Parties strive towards strictly protecting threatened migratory species (Appendix I species) and conserving or restoring the places where they live, mitigating obstacles to migration and controlling other factors that threaten them (CMS, 2017). Non-endangered species with unfavorable conservation status (Appendix II species) that would benefit from international cooperation, are also addressed by the Convention. As well as establishing obligations for CMS Parties, the Convention, promotes concerted action among the range states of migratory species (CMS, 2017). CMS's 11th Conference of the Parties adopted the Strategic Plan for Migratory Species 2015–2023 which has five Goals consisting of 16 Targets (CMS, 2014). Indicators for measuring progress towards these are still in development.

Mainstreaming relevant conservation and sustainable use priorities across government and society to address the underlying causes of decline of migratory species (Goal 1) is underway, but progress has been slow. World Migratory Bird Day has been celebrated annually since 2006, with events now held in over 130 countries worldwide stimulating conservation of migratory birds and raising awareness about the need for their conservation (Target 1; Caddell 2013a, CMS, 2016). Other efforts to raise awareness of migratory species and the steps needed to conserve them have included the 'Year of the Bat' (2017) and similar initiatives for gorillas (2007) and dolphins (2009), but the impact of these initiatives on awareness has not been systematically assessed. Little information is available on the degree to which the values of migratory species and their habitats have been integrated into development and poverty reduction strategies and planning processes and incorporated into national accounting (Target 2).

CMS coordinates the development and implementation of multilateral agreements among countries that share migratory species (Caddell 2013b). Migratory waterbirds, seabirds, cetaceans and bats are among the species groups covered by formal protocols concluded under the Convention. In the case of migratory birds, intergovernmental efforts to identify flyways and coordinate action have been highly successful. For most parts of the world, the policies and processes to secure the well-being of flyways is in place, but the challenge lies in implementing them (Boere & Piersma, 2012). Hence, progress has been made towards improving national, regional and international governance arrangements and agreements affecting migratory species, and to make relevant policy, legislative and implementation processes more coherent, accountable, transparent, participatory, equitable and inclusive (Target 3). Insufficient information is available to assess progress towards ending or reforming incentives, including subsidies that are harmful to migratory species, and to developing and applying positive incentives to their conservation (Target 4).

The direct pressures on migratory species and their habitats have not decreased, and may be worsening, meaning we are not progressing towards achievement of Goal 2. Land-use change owing to agriculture is the most significant threat to terrestrial migratory species, affecting nearly 80% of all threatened and near-threatened migratory bird species (Flockhart *et al*., 2015; Kirby *et al*., 2008), while overexploitation and its indirect impacts is the biggest threat to migratory species in the marine environment (e.g., Croxall *et al*., 2012). Habitat conversion and degradation limit the degree to which many species can modify their migratory routes and may increase the threat from climate change (Robinson *et al*., 2009; Studds *et al*., 2017). Forest fragmentation and deforestation in breeding areas has contributed to the declines of Nearctic–Neotropical bird migrants (Bregman *et al*., 2014; Flockhart *et al*., 2015) and Afro-Palaearctic migrants (Vickery *et al*., 2014). In non-breeding areas, the interaction between habitat degradation and climatic conditions (in particular, drought) are also possible factors (Taylor & Stutchbury, 2016; Vickery *et al*., 2014). Infrastructure development including wind turbines, cables, towers and masts can also be a threat, particularly to migratory soaring bird species (Angelov *et al*., 2013; Bellebaum *et al*., 2013; Kirby *et al*., 2008) and migratory bats. Overharvesting and persecution, often illegal, remain serious threats, particularly at key migration locations (Brochet *et al*., 2016, 2017; Harris *et al*., 2011; Ogada *et al*., 2012). Climate change is negatively affecting many bird species already and is expected to exacerbate these pressures (Howard *et al*., 2018) as well as increasing competition between migratory and non-migratory species (Robinson *et al*., 2009). Climate change may have significant negative effects on the population size of 84% of migratory bird species, which is comparable to the proportion affected by all other anthropogenic threats (80%) (Kuletz *et al*., 2014; Robinson *et al*., 2009). Protected areas can help to mitigate some threats, but just 9% of migratory bird species are adequately covered by protected areas across all stages of their annual cycle, compared with 45% of non-migratory species, a pattern driven by protected area placement that does not cover the full annual cycle of migratory species (Martin *et al*., 2007; Runge *et al*., 2015).

The conservation status of migratory species and the ecological connectivity and resilience of their habitats is worsening, meaning that we are moving away from achievement of Goal 3. More than 11% of migratory land- and waterbirds are threatened or Near Threatened on the IUCN Red List (Kirby *et al*., 2008). Since 1988, the Red List Index shows that migratory birds have become more threatened, with 33 species deteriorating sufficiently to move to higher categories of threat on the IUCN Red List, and only six improving in status to qualify for downlisting (Kirby *et al*., 2008). More than half of migratory bird species across all major flyways have undergone population declines over the past 30 years (Kirby *et al*., 2008). There is increasing evidence of regional-scale declines in migrant birds: more Nearctic–Neotropical migrants have declined than increased in North America since the 1980s, and more Palearctic–Afrotropical migrants breeding in Europe declined than increased during 1970–2000. Regional assessments show that 51% of migratory raptors species in the African–Eurasian region and 33% of species in Central, South and East Asia have unfavorable conservation status. Some species appear to be particularly affected by declines in habitat extent and condition in non-breeding areas, notably in arid areas of tropical Africa (Kirby *et al*., 2008).

The prospect for large-bodied ungulates is no better. Mass migrations for six large-bodied ungulate species are extinct or unknown (Harris *et al*., 2009). With the exception of a few ungulates (such as Common Wildebeest *Connochaetes taurinus* and other migrants in the Serengeti Mara Ecosystem, White-eared Kob *Kobus kob* and Tiang *Damaliscus lunatus* in Sudan, and some Caribou *Rangifer tarandus* populations), the abundance of all other large-bodied migrant ungulates has declined (Harris *et al*., 2009). In the case of migratory species occurring in the marine environment, 21% are classified as threatened (i.e. categorized as Critically Endangered, Endangered or Vulnerable) with an additional 27% classified as Near Threatened or Data Deficient (Lascelles *et al*., 2014). Sea turtles are the most threatened group (85%), followed by seabirds (27%), cartilaginous fish (26%), marine mammals (15%) and bony fish (11%). Migratory species in marine ecosystems may be even more affected by climate change impacts than terrestrial species (Robinson *et al*., 2009). Highly migratory and straddling marine fishes (i.e., fish species that move through or exist in more than one exclusive economic zone) are further governed by the United Nations Fish Stocks Agreement (UNFSA), which has been in force since 2001. The objective of UNFSA is to "ensure the long-term conservation and sustainable use of straddling fish stocks and highly migratory fish stocks" (UNFSA, 2018). A recent assessment of global progress towards implementing this agreement concluded that the overall status of migratory fish stocks and straddling fish stocks had not improved since the 2006 Review Conference (Baez *et al*., 2016). Moreover, since 2010, there has been a decline in the overall status of highly migratory fish stocks and straddling stocks, and 60% of shark species are considered to be potentially overexploited or depleted (Baez *et al*., 2016).

There is little information to assess progress towards enhancing the benefits to all from the favourable conservation status of migratory species (Goal 4). Some progress has been made towards enhancing implementation through participatory planning, knowledge management and capacity-building (Goal 5). CMS Strategic Plan 2006–2011 and the Bali Strategic Plan for Technology Support and Capacity-Building provide the framework for capacity-building (CMS, 2018)**.** The Convention promotes a bottom-up and participatory approach in identifying specific objectives, strategies and activities for implementation by governments, NGOs and other stakeholders. Collaboration with NGOs to facilitate implementation and capacity-building has increased over the years, enabling cost-sharing, especially in developing and emerging economies (Prideaux, 2015), despite some NGO relationships with CMS instruments tending to be *ad hoc*, with some key discussions closed to them (Prideaux, 2014). National Biodiversity Strategy and Action Plans (NBSAPs) often fail to consider adequately the needs of migratory species which are typically not endemic or may not comprise a significant component of the local biodiversity (CMS, 2017).

3.4.2 The Convention on International Trade in Endangered Species of Wild Fauna and Flora

In force since 1975, CITES aims to ensure that international trade in specimens of wild animals and plants does not threaten their survival (CITES, 2017). The primary policy tool of CITES is the regulation of trade to avoid utilization incompatible with species' survival (Appendix II listed species) and the prohibition of trade for commercial purposes on all species listed in Appendix I (e.g., leopard *Panthera pardus*, sea turtles, bowhead whale *Balaena mysticetus*, and the monkey-puzzle tree *Araucaria araucana*). The Convention contains a number of exceptions to this general prohibition, however (CITES, 2017). It controls international trade of selected species through a licensing system that requires authorization of all import, export or re-export of all species covered. CITES presently exercises responsibility over almost 35,600 species of flora and fauna (CITES, 2017). Only 3% of these are under Appendix I. CITES has 183 Parties, which have adopted three goals outlined in the Convention's Strategic Vision (2008–2020) (CITES, 2017). The goals address compliance with, and implementation and enforcement of, the Convention (Goal 1), securing financial resources for Convention implementation and operationalization (Goal 2), and ensuring coherence and support between CITES and other multilateral agreements such as the CBD, CMS and relevant SDGs (Goal 3).

Trade in wildlife is increasing: on average, over 100 million individuals were traded annually during 2005–2014 compared with a mean of 9 million per year during 1975–1985 (Harfoot *et al*., 2018). Overall, trade seems to have shifted towards captive-bred rather than wild-sourced individuals for many (but not all) taxa (Harfoot *et al*., 2018).

Implementation compliance and enforcement of CITES is improving, but slowly, (Nowell, 2012) and trade bans are possibly worsening the situation for some species (Conrad, 2012; Santos *et al*., 2011), so progress towards Goal 1 has been moderate. Controls and bans on trade have been successful in helping to stabilize populations of certain species (Conrad, 2012; Gehring & Ruffing, 2008) such as the endangered Giant Otter *Pteronura brasiliensis* (Uscamaita & Bodmer, 2009), and spotted cats and crocodilians (Ginsberg, 2002), with some taxa showing modest population recoveries (e.g., Citron-crested Cockatoo *Cacatua sulphurea citrinocristata*; Cahill *et al*., 2006). However, unsustainable levels of wildlife trade, some of which is legal and international, continue to pose major threats to global biodiversity (Joppa *et al*., 2016; Santos *et al*., 2011). The conservation status of some species, such as Lear's Macaw *Anodorhynchus leari* and Imperial *Amazona imperialis* has improved (toward less threatened categories of the IUCN Red List) as a consequence of control of trapping and trade, including through CITES regulations, but many more species have deteriorated in status toward more threatened categories owing to unsustainable harvests driven in part by international trade (Butchart, 2008; Di Marco *et al*., 2014; Hoffmann *et al*., 2010). In some cases, bans on legal trade drive increases in illegal trade, further threatening species already at risk (Di Minin *et al*., 2016; Fischer, 2010; Rivalan *et al*., 2007). Globalization and the interlinks between organized crime, terror organizations, social conflict and illegal wildlife trade also play a key role, particularly in the recent precipitous decline of elephant and rhino species in Africa and Asia (Brashares *et al*., 2014; Sollund, 2016; Wasser *et al*., 2009; but see UNODC, 2016).

Violations of the agreement are widespread (e.g., Dongol *et al*., 2012), while trade quotas typically do not consider population dynamics and are not based on population modelling (Smith *et al.,* 2011) despite evidence that such approaches are critical for many of the species impacted by international trade (e.g., Balme *et al*., 2012; Valle *et al*., 2018). The introduction of stricter legislation, wildlife trade controls and penalties in a number of countries led to improvements in compliance during 2010–2012 (Nowell, 2012). Nevertheless, major prosecutions for wildlife crime are still rare, and overall, enforcement has lagged behind compliance, despite examples of national scale bans combined with CITES restrictions decreasing unsustainable wildlife trade (Santos *et al*., 2011). Biennial reporting was virtually moribund (Reeve, 2006) and has subsequently been replaced with the requirement for an Implementation Report covering the three-year cycles between CITES Conferences of the Parties (CITES 2018a). CITES also requires Parties to submit annual trade reports and annual illegal trade reports (CITES 2018b). Non-compliance on annual reporting of trade and illegal trade is common, however, limiting the reliability of conclusions drawn from trade statistics generated from such reports (Challender *et al*., 2015b; Foster *et al*., 2016; Phelps, 2010; Underwood *et al*., 2013).

Financial and other resources for the operation and implementation of CITES have been insufficient and are declining, meaning that we are moving away from achieving Goal 2**.** Funding remains a principal limitation to the effectiveness of CITES, especially for on-the-ground execution of mandates and for proposed enhancements (Phelps *et al*., 2010). The core administrative costs of the Secretariat, the Conference of the Parties and various committees are financed from the CITES Trust Fund which is replenished from contributions from the Parties to the Convention (CITES, 2017). Its annual budget of US$6 million is shrinking in real terms, even though Parties agreed to an increase of 0.24% in 2016. As of 31 July 2017, contributing Parties have failed to pay a total of nearly USD 850,000 for 2016 and prior years that they owe to the Trust Fund (CITES, 2017). As a 'pre-Rio' Convention, CITES cannot directly access the Global Environment Facility (Reeve, 2006). Nevertheless, during the period 1 January 2016 to 31 July 2017, CITES received USD 14.3 million in voluntary contributions to its Trust Fund. Lack of funding is one of the reasons that Parties are reluctant to establish a dedicated compliance or implementation committee (Nowell, 2012).

CITES and other multilateral instruments and processes are generally coherent and mutually supportive, meaning that there is good progress towards Goal 3**.** CITES actively engages with allied biodiversity MEAs, most significantly with the Ramsar Convention, WHC, CMS, CBD, and ITPGRFA (with which it cooperates under a body called the 'Liaison Group of Biodiversity-related Conventions' to explore opportunities for synergistic activities and increased coordination, and to exchange information; CITES, 2018c; Couzens, 2013; Yeater, 2013). Given its focus on international trade, MEA counterparts tend to refer to CITES on issues of trade and transportation permits, while the CMS has advocated close engagement with CITES and encouraged application of the lessons learned through CITES implementation (Caddell, 2013a). Although there is high level of inter-treaty cooperation (Caddell, 2012, 2013b), opportunities for enhancing synergies remain untapped (Ministry of the Environment of Finland 2010), e.g., in relation to taxonomy and reporting (Phelps *et al*., 2010). One multilateral process in which alignment with

CITES has been challenging is the International Whaling Convention, with which there has been disagreement on the hierarchical arrangement between the two regimes (Caddell, 2012, 2013b).

3.4.3 The Ramsar Convention on Wetlands

The Ramsar Convention addresses the conservation and wise use of wetlands and has 170 Parties. The four Goals of the Convention's 4th Strategic Plan (2016–2024) relate to addressing the drivers of wetlands loss and degradation (Goal 1), the effective conservation and management of the Ramsar Site network (Goal 2), wise use of all wetlands (Goal 3), and enhanced implementation of the Convention (Goal 4). Wetland loss is continuing because of poor progress in addressing the drivers of wetland loss, meaning we are moving away from achieving Goal 1. The long-term loss of natural wetlands was 54–57% since 18th century, while during the 20th and early 21st centuries the rate of loss significantly increased with a loss of 64–71% of wetlands since 1900 AD, based on a subset of sites with available data (Davidson, 2014). Although the rate of wetland lost slowed down in North America and Europe since 1980s (Davidson, 2014), 4.8% of marshes and bogs have been lost in Europe during 1990–2006 (EEA, 2015, p 18), and 80,000 acres of wetlands were lost annually during 2004–2009 in coastal watersheds in the conterminous United States (Dahl & Stedman, 2013). The rates of wetland loss remain high in Asia (Russi *et al*., 2012, p. 19–20) with, for example, an average annual loss of 1.6% of the area of wetlands in Northeast and South-East Asia (Gopal, 2013; UNEP, 2016b, p.65), 65% loss of intertidal wetlands in the Yellow Sea over the past 50 years (Murray *et al*., 2014), and loss of 51% of coastal wetlands in China, 40% in the Republic of Korea and >70% in Singapore during 1955–2005 (MacKinnon *et al*., 2012, p.1). There is limited information on wetland loss in Africa, Latin America and the Caribbean and Oceania (Davidson, 2014). The Red List Index for wetland birds, mammals and amphibians, plus corals, is continuing to decline, indicating that overall, these species are moving towards extinction (Ramsar Convention, 2018).

Wetland benefits feature in some national/local policy strategies and plans in key sectors, for example the US Agricultural Act of 2014 has funding schemes for wetland conservation (USDA, 2017) while the EU Water Framework Directive (2000) features wetlands in integrated river basin management plans to improve water quality. However, there are large gaps; for example, many wetlands in India are under anthropogenic pressures because wetlands barely figure in water resource management and development plans (Bassi, 2014), while the absence of wetland considerations in local land-use planning is the main driver for wetland degradation in the Mediterranean (Mediterranean Wetlands Observatory, 2012, p.44). Finlayson (2012) found that national-level implementation of the Ramsar Convention is, overall, inadequate. Wetlands in almost all regions continue to be degraded due to anthropogenic factors such as land claim for agriculture (e.g., in 1990–2006, 35% of wetlands loss in the EU was to agriculture; EEA, 2015, p.18; Murray *et al*., 2014; Russi *et al*., 2012), urbanization (Hettiarachchi *et al*., 2015) and pollution (Gopal, 2013; Junk *et al*., 2013; Ramsar Convention, 2018), although there are exceptions: the EU made significant progress in reducing nutrient levels in lakes and rivers between 1992 and 2007 by improving wastewater treatment and reducing agricultural inputs (EEA, 2015, p.70). Ramsar COP 12 National Reports show that in many countries some parts of public and private sectors are applying guidelines for the wise use of water and wetlands; however, there is no evidence to access the scale and effectiveness of this.

Invasive alien species threaten native biodiversity (Lodge *et al*., 2006), with wetlands being particularly susceptible to invasions (Zedler & Kercher, 2004). In Europe, the cumulative number of alien species in freshwater, marine and estuarine ecosystems has been constantly increasing since the 1900s. The trend is slowing down for freshwater species, but not for alien marine and estuarine species (EEA, 2010). In 2018, 40% of Ramsar Parties had developed a comprehensive national inventory of invasive alien species impacting wetlands, but only 26% had established national policies or guidance on control or management of invasive alien species impacting wetlands (Ramsar Convention, 2018). Information about wetland invasive alien species is increasingly accessible through the Global Invasive Species Database (http://www.iucngisd.org/gisd/).

Parties do not appear to be on track to achieve effective conservation and management of the Ramsar site network (Goal 2). Only c. 11% of inland wetlands are designated as national protected areas and/or Ramsar Sites, ranging from 20% in Central and 18% in South America to only 8% in Asia (Reis *et al*., 2017). While 2,314 Wetlands of International Importance covering 245.6 million ha had been designated Ramsar Sites as of August 2018, ecological representation remains low. Only 24% of 3,359 wetland Important Bird and Biodiversity Areas (IBAs) that qualify as Ramsar Sites had been designated under the convention by March 2015, representing 14% of the area of all qualifying sites. Coverage is highest in Europe and Africa (with at least 30% of qualifying IBAs completely or partially covered) and lowest in Asia (just 12% completely or partially covered); results for the Americas and the Pacific are currently unavailable. The percentage of qualifying IBAs completely or partially covered by Ramsar Sites has increased from 16% in 2000 to 24% in 2015 (BirdLife International, 2015). The rate of designation of Ramsar Sites has slowed considerably in the 2010s, and only

41% of Parties have established a strategy and priorities for future Ramsar Site designation (Ramsar Convention, 2018). Only slightly more than half of all Ramsar Sites have management plans that are being actively implemented (Ramsar Convention, 2018).

Progress towards wise use of all wetlands (Goal 3) has been poor. Wetland inventories are missing, incomplete or out of date in many countries (Junk *et al*., 2013), although the recent publication of a global wetland layer based on remote sensing (Pekel *et al*., 2016) may help to address this issue. Based on 140 National Reports (2018), 44% of Contracting Parties have completed National Wetlands Inventories and 29% are in progress. The proportion of Parties having completed inventories is highest in North America (67%) and Europe (62%) and lowest in Asia (30%). In 2015, 37% of Parties to the Ramsar Convention reported that they have removed perverse incentives that discourage the conservation and wise use of wetlands, while 51% reported that actions had been taken to implement positive incentives that encourage the conservation and wise use of wetlands (Ramsar Convention, 2018). By 2018, 73 Parties had established a National Wetland Policy or equivalent, and 18 additional countries have elements of such a policy in place (Ramsar Convention, 2018). Integrated resource management at the scale of river basins and coastal zones is often insufficient.

While traditional knowledge, innovations and practices of IPLCs are sometimes integrated into implementation of the Convention, this does not happen universally, despite the fact that engaging local actors in rule development typically leads to greater consensus and more effective multilateral implementation (Mauerhofer *et al*., 2015). Wetland functions, services and benefits are widely demonstrated, documented and disseminated (Ghermandi *et al*., 2010; Ramsar Convention, 2018). While some efforts are underway to restore degraded wetlands (e.g., Cui *et al*., 2009; Zhao *et al*., 2016b,), climate change is likely to exacerbate the pressures on wetlands (Finlayson *et al*., 2017; Gopal, 2013; Junk *et al*., 2013).

Implementation of the Ramsar Convention is being strengthened, but slowly (Goal 4). Scientific and technical guidance on relevant topics are increasingly available and used by policy makers and practitioners (e.g., Ramsar guidance shaped the governance of urban wetlands in Colombo, Sri Lanka; Hettiarachchi *et al*., 2015). The Ramsar Convention's Programme on communication, capacity-building, education, participation and awareness promotes World Wetland Day to mainstream wise use of wetlands. To assist in implementing the Convention, 19 Ramsar Regional Initiatives, including networks of regional cooperation such as the Niger River Basin Network and the West African Coastal Zone Wetlands Network, have been developed.

3.4.4 United Nations Convention to Combat Desertification (UNCCD)

The UNCCD has a strategic plan for 2008–2018 which sets four long-term strategic goals and five short- and medium-term operational objectives (UNCCD, 2007). The goals aim to: improve living conditions of the communities (Goal 1) and the ecosystems (Goal 2) affected by land degradation and desertification; generate global benefits for biodiversity conservation and climate change mitigation (Goal 3); and mobilize resources and build partnerships for implementation of the Convention (Goal 4).

There has been poor progress towards improving the living conditions of affected populations (Goal 1). Desertification and land degradation are roughly estimated to affect over 1.5 billion people whose livelihoods and well-being are dependent on dryland areas and agriculture (Amiraslani & Dragovich, 2011; Bai *et al*., 2008; Sanz *et al*., 2017 p.29,). Adverse effects of land degradation have most impact on the poor and vulnerable social groups (IPBES, 2018). Globally, 74% of the poor (42% of the very poor and 32% of the moderately poor) are directly affected by land degradation (Sanz *et al*., 2017). About 20% of irrigated land (45 million hectares) is moderately or severely salinized (Rengasamy, 2006), including the Indo-Gangetic Basin in India (Gupta & Abrol, 2000), Aral Sea Basin of Central Asia (Cai *et al*., 2003), and the Murray-Darling Basin in Australia (Rengasamy, 2006). Desertification undermines affected people's livelihoods and contributes to increased levels of poverty and rural-urban migration (Amiraslani, 2011; Bates, 2002; Verstraete, 2009). Although migration is often caused by a mix of social, economic, political and environmental drivers (Warner *et al*., 2010), 'environmental migrants' outnumber traditional socio-political refugees in sub-Saharan Africa (Myers, 2002). Desertification may displace globally 50 million people in the next 10 years (Sanz *et al*., 2017). Since the mid-20th century, there has been increasing aridification of Africa, East and Southern Asia, Eastern Australia, and Southern Europe (Dai, 2011; Sheffield *et al*., 2009). Under a 'business-as-usual' scenario, up to 50% of the earth's surface may be in drought at the end of the 21st (Burke *et al*., 2006). Increasing droughts may further jeopardize the livelihoods and well-being of communities dependent on agriculture (Morton, 2007).

There seems to be a moderate progress towards improving the condition of affected ecosystems (Goal 2). There has been 'some progress' towards UNCCD targets related to deforestation, but 'little or no progress' towards those related to desertification and drought (UNEP, 2012). While some subtropical deserts (e.g., the Sahara, Arabian, Kalahari, Gobi and Great Sandy Desert) are expanding (Zeng & Yoon, 2009), some arid territories such as the Sahel, the Mediterranean basin, Southern Africa are currently 'greening up' and are not expanding (Hellden & Tottrup, 2008). Estimates of the global area of degraded land range between 1 and 6 billion ha (Gibbs and Salmon, 2015). Of the c. 24% of global land area that is degrading, 23% is broadleaved forest, 19% is needle-leaved forest, and 20–25% is rangeland (Bai *et al*., 2008). One of the drivers is land conversion for agricultural expansion (Lambin & Meyfroidt, 2011), especially in the tropical forest regions (Gibbs *et al*., 2010; Keenan *et al*., 2015). Desertification also contributes to the emission and long-range transport of fine mineral dust (D'Odorico *et al*., 2013), which may adversely affect ecosystems ranging from lowlands to mountain glaciers (Indoitu *et al*., 2015).

We appear to be making moderate progress in generating global benefits for the conservation and sustainable use of biodiversity and the mitigation of climate change through implementation of the convention (Goal 3). Land degradation, affecting about 25% of global land area (Bai *et al*., 2008), influences in a complex way the magnitude and direction of climate impacts on agricultural land and biodiversity (Webb *et al*., 2017). Practices and technologies that mitigate land degradation, climate change adaptation and mitigation often positively affect biodiversity (Sanz *et al*., 2017, p. 81). Climate change is likely to affect agricultural yields and threaten future global food security (World Bank, 2008, p. 100) and reduce communities' adaptability and resilience towards climate change (Neely *et al*., 2009). Net greenhouse gas emissions from land-use changes amounted to approximately 10–12% of total emissions around the year 2005 (Sanz *et al*., 2017, p. 35). Although CO2 emissions from net forest conversion in 2011–2015 decreased significantly since 2001–2010 period, the share of CO2 emissions from forest degradation increased (Federici *et al*., 2015). Global emissions from land use, land use change and forestry decreased from 1.54±1.06 $GtCO_2e\ yr^{-1}$ in 1990 to 0.01±0.86 $GtCO_2e\ yr^{-1}$ in 2010, and future net emissions by 2030 range from an increase of 1.94 ± 1.53 $GtCO_2e$ yr–1 to a decrease of –1.14±0.48 $GtCO_2e\ yr^{-1}$ under different policy scenarios (Grassi *et al*., 2017). Reducing agriculture-driven deforestation and forest-sparing interventions could reduce 1-1.3 $GtCO_2e\ yr^{-1}$ from the agriculture sector (Carter *et al*., 2015). Most countries (89%) have included agriculture and/or land use, land-use change and forestry (LULUCF) in emission reduction targets in their Intended Nationally Determined Contributions (Sanz *et al*., 2017, p.37).

Good progress has been made in mobilizing resources to support implementation of the Convention through building effective partnerships between national and international actors (Goal 4). UNCCD has committed to harmonize its strategies with the SDGs and direct its activities to meet SDG 15.3 (to combat desertification and restore degraded land and soil… and strive to achieve a land degradation-neutral world). With support from the convention, 102 countries agreed in 2016 to set voluntary Land Degradation Neutrality targets. The formal agreement of the definition of Land Degradation Neutrality in 2015 (UNCCD, 2015) was followed by the development of a Scientific Conceptual Framework for Land Degradation Neutrality, which takes into account quantitative and qualitative data and emphasizes stakeholder participation (Akhtar-Schuster *et al*. 2017; Cowie *et al*., 2018; Orr *et al*., 2017).

UNCCD has developed a monitoring and assessment framework, which takes into account quantitative and qualitative data and emphasizes stakeholder participation (Akhtar-Schuster *et al*., 2017). There are some challenges in operationalizing indicators against these targets (Chasek *et al*., 2015; Dooley & Wunder, 2015; Sietz *et al*., 2017), a lack of baseline data for assessing progress (Grainger, 2015) and no uniform criteria and standard methodology to assess land degradation and the effectiveness of restoration measures; nevertheless, progress towards setting Land Degradation Neutrality targets appears to be significant.

3.4.5 The Convention concerning the Protection of the World Cultural and Natural Heritage

The WHC was adopted by the General Conference of the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 1972, and came into force in December 1975. The Convention seeks to encourage the identification and conservation of natural and cultural heritage of 'Outstanding Universal Value', which is defined as 'cultural and/or natural significance which is so exceptional as to transcend national boundaries and to be of common importance for present and future generations of all humanity' (UNESCO WHC, 2016). The Convention requires its 193 Parties to identify and protect relevant sites (UNESCO WHC, 2017). The WHC is the most universal international legal instrument for global protection of cultural and natural heritage.

World Heritage Sites are landmarks or areas of outstanding universal value that have been officially recognized by UNESCO, following decisions from the intergovernmental World Heritage Committee. Signatories have to conserve both world heritage and national heritage in their countries. As of April 2018, there are 1,092 sites on the World Heritage List, of which 209 sites are classified as 'natural' heritage, 845 as 'cultural' heritage and 38 as 'mixed' heritage (i.e., natural and cultural) (UNESCO, 2018). Natural heritage sites include natural features, geological and physiographical formations, and natural areas with aesthetical, scientific and conservation value. Parties are encouraged to integrate cultural and natural heritage protection into regional planning programmes, undertake relevant conservation research, and enhance the function of heritage in people's lives. The World

Heritage Committee may inscribe a property on the 'List of World Heritage in Danger'. At present, 16 of the 54 sites on this list are natural sites (UNESCO, 2018). Annual reviews are required of the state of conservation of properties on the List.

In 1994, the World Heritage Committee launched a Global Strategy for a Representative, Balanced and Credible World Heritage List to ensure that it reflects the world's cultural and natural diversity of outstanding universal value. In 2002, at its 26th Session of the Committee, the Budapest Declaration on World Heritage was adopted, setting out four main objectives of the Convention; a fifth was added in 2007. In November 2017, UNESCO published the World Heritage Outlook 2, which assessed the conservation status of 241 natural and mixed sites.

Good progress has been made to strengthen the credibility of the World Heritage List as a representative and geographically balanced testimony of cultural and natural properties of outstanding universal value (Objective 1). The number of States (i.e. Parties) to the WHC has risen from 139 to 167 in the last 20 years, with the number of sites listed growing from 33 to 1,092 (UNESCO, 2018). The list of sites is often accused of being highly biased, with Europe and North America having 47% of all sites (23% of all natural sites) while sub-Saharan Africa and the Arabian countries, for example, have 9% and 8% of all sites, respectively (Frey *et al*., 2013; Bertacchini and Saccone, 2012). In an effort to improve geographic representativeness, the WHS Secretariat has encouraged more countries to submit Tentative Lists for consideration (183 States have done this so far; UNESCO, 2018). Evaluations of the representativeness of World Heritage Sites indicate that they provide highly uneven biodiversity coverage, and underrepresent tropical and subtropical coniferous forests, temperate grasslands, Mediterranean forests, and tropical and subtropical dry forests (Anthamatten & Hazen, 2007; Bertzky, *et al*., 2013; Brooks *et al*., 2009). These biomes, however, are also poorly represented by protected areas more generally (Anthamatten & Hazen, 2007). Moreover, some Parties do not have any inscribed sites, even though they may possess sites likely to fulfil the selection criterion of 'outstanding universal value' (Frey *et al*., 2013). The dominance of the national over the international interest in World Heritage Site selection has also been noted (Frey *et al*., 2013).

Poor progress has been made in ensuring the effective conservation of World Heritage properties, particularly natural sites (Objective 2). Natural World Heritage sites are facing a wide range of threats, particularly invasive species, tourism, commercial hunting, fishing, dams and logging (Osipova *et al*., 2014, 2017). The two most significant current threats to natural World Heritage are invasive species and climate change **(Figure 3.14)**. Tourism impacts, legal and illegal fishing and hunting, fires, water pollution and dams are among the top threats. Between 2014 and 2017, the number of sites for which climate change was assessed as high or very high threat almost doubled, while the threat of fires increased by 33% (from 27 to 36 sites) (Osipova *et al*., 2017). Regional differences in current threat assessments exist. The highest number of sites where climate change was assessed as a high or very high current threat were in Oceania and Mesoamerica and the Caribbean. Oceania and North America have the most sites where invasive species are a high or very high threat. Europe and Asia have the most sites where tourism is a high or very high threat.

Only about half of the natural sites on the World Heritage List are regularly monitored through the main monitoring mechanisms of the Convention (Osipova *et al*., 2014). For those regions where Key Biodiversity Areas have been comprehensively assessed, all natural and mixed World Heritage sites have been found to qualify as Key Biodiversity Areas (Foster *et al*., 2010). For almost two thirds of all sites (64%) the conservation outlook is either good or good with some concerns, for 29% of sites the outlook is of significant concern, and for 7% it is critical (Osipova *et al*., 2017). Some World Heritage sites are additionally recognized as fulfilling the criteria for Outstanding Universal Value, defined as having "cultural and/or natural significance which is so exceptional as to transcend national boundaries and to be of common importance for present and future generations of all humanity" (UNESCO, 2016). For 70% of World Heritage sites, the values for which they were listed are either in a good state or of low concern, whereas for 27% and in 5% of sites the current state is of high concern or critical, respectively **(Figure 3.14)**. In 2014, the values associated with geoheritage (criterion viii) were in the best condition, with 94% of cases assessed as either good or of low concern. The values associated with biodiversity have tended to be of higher concern (Osipova *et al*., 2014, 2017).

Osipova *et al*. (2017) assessed 14 criteria for site protection and management and concluded that "only 48% of sites have overall effective or highly effective protection and management and in 12% of sites protection and management are of serious concern". Protection and management effectiveness decreased between 2014 and 2017, with the most effective criterion being research while sustainable finance was the criterion of highest concern. Good progress is being made in promoting the development of effective capacity-building measures, including for preparing site nominations and implementing the Convention (Objective 3). World Heritage programmes addressing this objective include resource manuals to help Parties nominate sites, to manage natural and cultural values within them, and to manage of disaster risks, and capacity-building. However, there is no independent

Figure 3 14 **A Conservation Outlook rating of 241 natural World Heritage sites, and B threats to natural World Heritage sites assessed as high or very high in 2014 and 2017.**

Source: Osipova *et al.*,(2017).

information on the effectiveness of these measures in building capacity.

Recent improved communication efforts have increased public awareness, involvement and support for World Heritage, indicating progress towards Objective 4, but information to assess this robustly is lacking. Awareness is likely to have been raised through the publication of the World Heritage Paper Series (launched in 2002), the dissemination of the quarterly World Heritage Review and World Heritage Newsletter, through the World Heritage Volunteers Initiative, the World Heritage Education Programme and the recent publication of the World Heritage Outlook 2.

The role of communities in the implementation of the World Heritage Convention is likely to have been enhanced, but at an insufficient rate (Objective 5). Programmes such as the World Heritage Volunteers Initiative and World Heritage Education Programme are likely to have increased community involvement, and there are a number of examples of sustainable development at World Heritage Sites being achieved through the involvement of local communities and the integration of multiple values and traditional and local ecological knowledge (Galla, 2012). In terms of relationships with local people, a criterion that was assessed in Outlook 2, it was considered highly effective in 35 sites and of serious concern for 22 sites of the 241 natural WHS (**Figure 3.14**; Osipova *et al*., 2017).

3.4.6 The International Plant Protection Convention

The IPPC has set four Strategic Goals for the period 2012–2019: A) to protect sustainable agriculture and enhance global food security through the prevention of pest spread; B) to protect the environment, forests and biodiversity from plant pests; C) to facilitate economic and trade development through the promotion of harmonized scientifically based phytosanitary measures; and D) to develop phytosanitary capacity for members to accomplish a), b) and c). IPPC's Strategic Goals contribute to the Strategic Objectives of the Food and Agriculture Organization of the United Nations, as well as to Sustainable Development Goals 8, 13, 15 and 17 and Aichi Target 9. Strategic Goal B is the one most closely related to conservation of biodiversity, while Goals A, C and D are more focused on agriculture and food security.

There is poor progress towards protecting sustainable agriculture and enhancing global food security through the prevention of pest spread (Goal A). Crop losses to pests have not significantly decreased during the last 40 years (Oerke, 2006). Analysis of the distribution of pests (arthropods, gastropods and nematodes), pathogens (fungi, oomycetes, protozoa, bacteria and viruses) and crops shows that more than one tenth of all pests have reached more than half the countries in which the crops they affect are grown. By the middle of the 21st century, these crop producing areas are likely to be fully saturated with pests (Bebber *et al*., 2014). Fungi and oomycetes are the most widespread and most rapidly spreading crop pests and make up the largest fraction of the 50 most rapidly spreading pests. Although some pests have global distributions, the majority of pest assemblages remain strongly regionalized, with their distributions determined by the distributions of their hosts (Bebber *et al*., 2014). Human activities remain the main factor facilitating spread of pests, although climate change may play a growing role in future. An average poleward shift of 2.7 ± 0.8 km yr−1 since 1960 has been observed for hundreds of pests and pathogens, with significant variation in trends among taxonomic groups (Bebber *et al*., 2013).

Global agricultural intensification is continuing in order to meet the increasing demand for food (Phalan *et al*., 2011; Tilman *et al*., 2011), but the associated landscape simplification negatively affects natural pest control. Growing agricultural expansion has a negative effect on biodiversity (Kehoe *et al*., 2017). Homogeneous landscapes dominated by cultivated land have 46% lower pest control levels than more complex landscapes. Conserving and restoring semi-natural habitats helps to maintain and enhance pest control services provided by predatory arthropods to agriculture (Rusch *et al*., 2016), and this also benefits biodiversity more broadly.

There is poor progress towards protecting the environment, forests and biodiversity from plant pests (Goal B). Biosecurity measures are critical for future food security (Cook *et al*., 2011), but pesticides remain the predominant measure for pest control in agriculture, with a >750% increase in pesticide production between 1955 and 2000 (Tilman *et al*., 2001). Broadscale and prophylactic use of some pest control measures such as insecticides may harm other organisms that are beneficial to agriculture, and in turn their ecological function, such as pollination (van der Sluijs *et al*., 2014; Whitehorn *et al*., 2012). Meta-analysis of 838 peer-reviewed studies (covering >2,500 sites in 73 countries) suggests that 52.4% (5,915 cases; 68.5% of the sites) of the 11,300 measured insecticide concentrations exceeded the accepted regulatory threshold levels for either surface water or sediments (Stehle & Schultz, 2015). High pesticide levels negatively affect freshwater invertebrate biodiversity (Beketov *et al*., 2013). Alternatives to intensive insecticide application include using more diverse crop rotations, altering the timing of planting, tillage and irrigation, using alternative crops in infested areas, applying biological control agents, and using lower-risk insecticides (Furlan & Kreutzweiser, 2015). Non-crop habitats at landscape scale tend to increase the diversity and/or the abundance of pests' natural enemies in fields (Attwood *et al*., 2008; Langelotto & Denno, 2004), which provides more effective control of herbivorous arthropods (Letourneau *et al*., 2009).

Good progress is being made to facilitate economic and trade development through the promotion of harmonized scientifically based phytosanitary measures (Goal C). The Agreement on the Application of Sanitary and Phytosanitary Measures is an important part of the World Trade Organization's Law of Domestic Regulation of Goods. Articles 2.2. and 5.6 require that sanitary and phytosanitary measures must not be trade-restrictive, and they must be based on scientific principles and applied only to the extent necessary to protect human, animal or plant life or health (Marceau & Trachtman, 2014). Sanitary and phytosanitary measures tend to restrict trade by increasing the costs for exporters of entering the market (Crivelli & Gröschl, 2015), especially for middle- and low-income exporting countries (Swinnen & Vandermoortele, 2011; Yue *et al*., 2010). Increasing stringency of such measures in developed countries has a substantial negative effect on exported volumes from developing countries (Melo *et al*., 2014). At the same time, these measures increase consumer confidence in product safety and positively affect trade of those exporters that comply with the requirements (Crivelli & Gröschl. 2015; Henson & Humphrey, 2010; Sheldon, 2012). Overall, such measures and their stringency do not tend to evolve uniformly across countries and regions (Woods *et al*., 2006) and the exporters capable of compliance tend to outcompete those which are not (Murina *et al*., 2015). Analysis of 47 fresh fruit and vegetable product imports into the USA from 89 exporting countries during 1996–2008 showed that sanitary and phytosanitary measures generally reduce trade in the early stages, but then their restrictiveness diminishes as exporters accumulate experience and reach a certain threshold (Peterson *et al*., 2013).

There has been moderate progress towards developing phytosanitary capacity for IPPC Parties to accomplish these goals (Goal D). Human-mediated pathways remain the main source of agricultural pest spread at global and regional scales (Bebber *et al*., 2013; Lopes-da-Silva *et al*., 2014). IPPC has developed the National Phytosanitary Capacity Development Strategy in 2012 as well as the Phytosanitary Capacity Evaluation tool. The latter provides a summary of a country's phytosanitary capacity at a particular time, which can be used for further strategic planning, priority setting and fundraising (IPPC, 2017).

Box 3 1 **Progress towards achieving the objectives of the United Nations Convention on the Law of the Sea (UNCLOS).**

Background on UNCLOS is given in section S3.11. Here we describe progress towards the objectives of UNCLOS Articles 61-68.

Progress in conserving fisheries stocks

Based on stock size and exploitation rates as indicators of a population's maximum sustainable yield, stocks overfished beyond biologically sustainable levels increased from 10% in 1974 to 31.4% in 2013. Of the stocks assessed in 2013, 58.1% were fully fished and only 10.5% were underfished (FAO, 2016). These assessments do not consider broader impacts such as those from by-catch, habitat and food web alteration. Since the 1950s, marine captures increased continuously until reaching a maximum of 86.4 million tonnes (mt) in 1996, but since then, captures have slowly declined, becoming relatively stable between 2003 and 2009, with slight growth to reach a new maximum in 2014 (81.5 mt), the last year fisheries catches were analyzed and reported globally (FAO, 2016). While global captures have been relatively stable, regional patterns have changed in response to local and regional changing conditions, deployment of new fishing technologies and increased fishing capacity (FAO, 2014a, 2016; Hazin *et al*., 2016; Rosenberg, 2016).

The largest marine fisheries landings are for Peruvian anchoveta, Alaska pollock, skipjack tuna, several sardine species, Atlantic herring, chub mackerel, scads, yellowfin tuna, Japanese anchovy and largehead hairtail. The trends for each of these groups or populations has been highly variable (FAO, 2016). In addition, climate change has already produced shifts in the distribution and productivity of some fisheries resources, especially those that are highly sensitive to changing oceanographic conditions (e.g., Peruvian anchoveta) (FAO, 2016; Rosenberg, 2016). Highlighting the most iconic fisheries, tuna captures reached a maximum in 2012 of 7 mt. For tuna and billfish, about half of the 41 assessed populations are under variable fishing pressures including being overfished or experiencing overfishing, or both (Restrepo *et al*., 2016; Inter-American Tropical Tuna Commission (IATTC) reports: https://www.iattc.org/StockAssessmentReports/StockAssessmentReportsENG.htm). For sharks (and other chondrichthyans), many populations are overexploited, with more than 2 mt of sharks captured per year, and some species are threatened. The shark fin market alone comprises more than 17,000 tonnes (Dulvy *et al*., 2017; Ward-Paige, 2017). Maximum global landings of sharks occurred in 2000 and have declined since then. These declines may be attributed to conservation management measures adopted by several RFMOs (e.g., prohibitions of catch for certain shark species; introduction of by-catch mitigation measures) (http://www.fao.

org/ipoa-sharks/regional-sharks-measures/en/), or to a change (and reduction) of consumption patterns in major markets including China (Vallianos *et al*., 2018). However, declines in landing have also been attributed to populations declines (Davidson *et al*., 2016).

Among invertebrates, the most valuable groups, lobster, shrimps and cephalopods (mostly squid), reached maximum levels of captures in 2014 (shrimp catches are stable around 3.5 mt and cephalopod catches exceeded 4.5 mt) (FAO, 2016). The areas where most global fisheries occur are the Northwest Pacific (27%), the Western Central Pacific (15%), the Southeast Pacific (11%) and the Northeast Atlantic (10%). About 18 countries are responsible for 76% of global captures (FAO, 2016).

In addition to the effects of captures on target species, there are also significant effects on by-catch species, ecosystems, food webs and benthic and demersal habitats (Hazin *et al*., 2016). While there has been increased awareness of these problems and efforts made to reduce by-catch and other broader ecosystem impacts of fishing, implementation of by-catch mitigation measures is variable, and there is insufficient monitoring of their success (Rosenberg, 2016).

Finally, catches in illegal, unreported and unregulated (IUU) fisheries, which have major negative effects on biodiversity, have been estimated to total 11-26 mt per year, concentrated in developing countries in particular. IUU fisheries have undermined the effectiveness of stock management measures (Gjerde *et al*., 2013). Success in reducing IUU fisheries varies across counties and regions and is highly related to governance (Agnew *et al*., 2009) and the effectiveness of law enforcement (Gjerde *et al*., 2013).

Progress in conserving other marine biodiversity

Best estimates of the proportion (with lower and upper estimates) of threatened species varies between taxonomic groups. In decreasing order these are: marine mammals 41% (28-60%); reef-building corals 33% (27-44%); sharks and rays 31% (18-59%); marine birds 20% (20-21%); marine reptiles (marine turtles, crocodiles and seasnakes) 20% (14-44%); hagfishes 20% (12-51%); mangroves 17% (16-21%); seagrasses 16% (14-26%); cone snails 8% (6-20%); selected marine bony fishes (sturgeons, tunas, billfishes, blennies, pufferfishes, angelfishes, butterflyfishes, surgeonfishes, tarpons, ladyfishes, groupers, wrasses, seabreams, picarels and porgies) 7% (6-18%); lobsters <1% (0-35%) (**Figure 3.15**; IUCN, 2017). The most threatened group, marine mammals, has seen the reduction of almost all populations since pre-exploitation times, with some species becoming extinct, such as Steller's Sea Cow *Hydrodamalis gigas* and Caribbean Monk Seal *Neomonachus tropicalis* (IUCN, 2017). Banning hunting has allowed for population recovery of the humpback whale *Megaptera novaeangliae* and blue whale *Balaenoptera musculus* following controls on commercial whaling. Protecting the feeding and breeding areas has also proved to be effective in the recovery of some marine mammal populations (Rodrigues *et al*., 2014). However, marine mammals still face many anthropogenic threats mostly due to habitat alterations (e.g., pollution, coastal development, noise) and climate change (Smith *et al*., 2016). The fact that there is a significant bias towards the study of less endangered species may also hinder the ability of policymakers to develop and apply the most appropriate conservation and management practices (Jaric *et al*., 2014).

The second most threatened group, corals, are impacted by a variety of stressors including pollution, sedimentation, physical destruction, overfishing, diseases, ocean acidification, and climate change. These stressors act synergistically with natural stresses and result in significant damage (Wilkinson *et al*., 2016), in particular the loss of live coral cover. In the Caribbean, average coral cover was reduced from 34.8% in the 1970s-1980s to 16.3% in ~2000-2010 (Jackson *et al*., 2014). At present, one of the major concerns is large-scale coral bleaching, which is associated with increasingly warming waters. Bleaching events have become more frequent, severe, and extensive, hindering the capacity of corals to recover (Hughes *et al*., 2017a, 2018). For example, the Great Barrier Reef suffered a bleaching event in 2015-2016 that affected 75% of surveyed locations.

Seabirds are threatened by pressures both at sea (e.g., fishing by-catch, pollution) and on land (e.g., disturbance, hunting, and predation by invasive species), and their status has deteriorated significantly in recent decades (Croxall *et al*., 2012; Lascelles *et al*., 2016). Almost 30% of 346 seabird species are globally threatened, and nearly half are known or suspected to have population declines (Croxall *et al*., 2012). Targeted conservation actions, including eradication of invasive species such as feral cats and rats from islands with seabird breeding colonies, and other actions focused on the most important marine and terrestrial locations for seabirds (identified as Important Bird and Biodiversity Areas) have improved the status of some populations and species (Croxall *et al*., 2012). FAO plans to reduce incidental by-catch of seabirds (http://www.fao.org/fishery/ipoa-seabirds/npoa/er/en) have not yet reduced this threat to seabirds (Croxall *et al*., 2012).

Trends in other groups of marine species (e.g., plankton, benthos, fish and pelagic macro-invertebrates, marine reptiles) and habitats are mostly negative (see the World Ocean Assessment (http://www.un.org/depts/los/global_reporting/WOA_RegProcess.htm; Rice, 2016). In general, no ocean biodiversity nor ecosystem has escaped the impact of human pressures. These pressures act either directly or indirectly and vary in intensity and spread. The most stressing impacts that act on marine biodiversity and ecosystems which also have societal and economic consequences are climate change (e.g., temperature increase and acidification), overfishing and human disturbance (e.g., catches, by-catches, collisions, net entanglement, habitat destruction), input of pollutants and solid waste to the ocean (e.g., nutrients, plastics, pathogens), increase in use of ocean space and physical alteration (e.g., shipping routes, wind farms, causeways, major channels), underwater noise, and introduction of invasive alien species (Bernal *et al*., 2016). Despite some progress in developing ecosystem-based approaches to manage human activities in the ocean, there is still a major need for assessments that integrate all environmental components across social and economic sectors for all parts of the world. To accomplish this, significant capacity development will be required (Bernal *et al*., 2016).

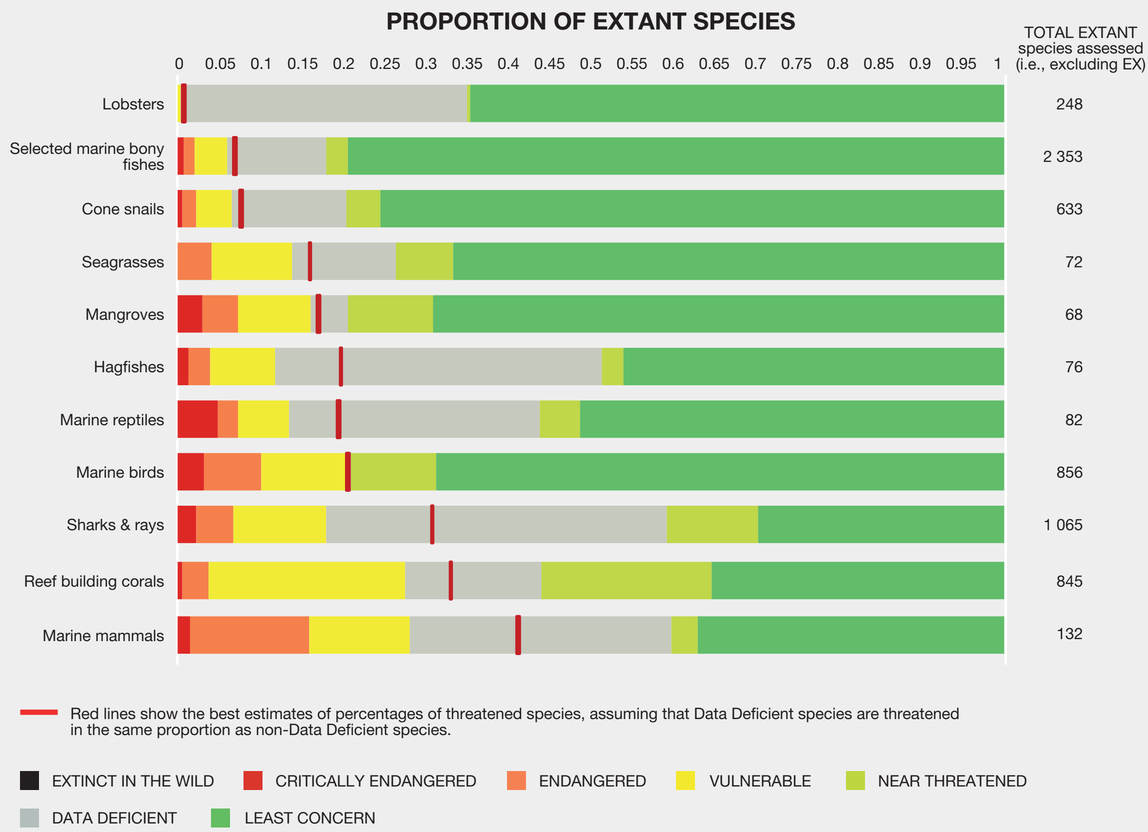


Figure 3 15 **The proportion of marine species in each category of extinction risk on the IUCN Red List.**

Groups are ordered according to the vertical red lines, which indicate the best estimate for proportion of extant species considered threatened (Critically Endangered or Vulnerable). The numbers to the right of each bar represent the total number of extant species assessed for each group. Extinct species are excluded. Source: IUCN (2017).

Protecting marine areas

For progress towards establishing marine protected areas, including description of Ecologically and Biologically Significant Areas (a process coordinated by the CBD), and the establishment of protected areas for biodiversity beyond national jurisdictions (a process managed through the United Nations General Assembly) see section 3.2. on Aichi Target 11.

Box 3 2 **Progress towards achieving the objectives of polar agreements and cooperative arrangements.**

The Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR)

Background on CCAMLR is given in section S3.12. Here we describe progress towards its objectives. CCAMLR has achieved considerable progress to meeting its goal of "conservation of Antarctic living resources". It is regarded as a leader in High Seas conservation (Brook, 2013) and in developing ecosystem-based fisheries management (Constable, 2011). Progress made towards achieving the goals of the Convention include: 1) the establishment and enforcement of fisheries controls, 2) the establishment Marine Protected Areas (MPAs) within the Convention area in accordance with international law (including UNCLOS), 3) the reduction of seabird mortality, 4) the establishment of the CCAMLR Ecosystem Monitoring Program (CEMP), and 5) the identification and management of vulnerable marine ecosystems (e.g., seamounts, hydrothermal vents, cold water corals and sponge fields).

With regard to fisheries, CCAMLR has implemented a series of measurements to address the impact of bottom fisheries (trawling or demersal long-lines) as well as to control illegal, unreported and unregulated (IUU) fishing. Such measures include the appointment of scientific observers under the CCAMLR Scheme of International Scientific Observation within every ship engaged in fisheries (Reid, 2011). This internationally recognized program has successfully improved the conservation of the seafloor and seabirds (Croxall, 2013) and the identification of vulnerable marine ecosystems (Reid, 2011). Such methods and encounter protocols developed for fishing vessels to identify and protect vulnerable marine ecosystems have led to calls for regulation of bottom fishing on the high seas (Reid, 2011). Bottom trawling has been banned around the Antarctic Peninsula since the early 1990s. Since then, some stocks have recovered in this area; however, neither the mackerel icefish *Champsocephalus gunnari*, one of the most abundant species before exploitation, nor the yellow notothenia *Gobionotethen gibberifrons* have yet recovered (Gutt *et al*., 2010).

With regard to the establishment of marine protected areas, CCAMLR has negotiated the establishment of important protected areas in the Southern Ocean, e.g., in the South Orkney Islands in 2010, and in the Ross Sea in 2016 (Brook, 2013; CCAMLR, 2016; UNEP-WCMC & IUCN, 2018). The marine protected area in the Ross Sea is the largest in the world, covering more than 2 million km^2 (CCAMLR, 2016). Another potential major protected area in the Weddell Sea is currently under consideration (Teschke *et al*., 2013, 2014).

Overexploitation of fisheries resources, mainly Antarctic toothfish *Dissostichus mawsoni*, Patagonian toothfish *D. eleginoides*, and mackerel icefish, along with bycatch, habitat loss, human disturbance, pollution and climate change are the major threats to marine biodiversity and ecosystems in the Southern Ocean (Alder *et al*., 2016; Griffiths, 2010). For seabirds, significant decreases in populations of species known to be caught on longline fisheries (e.g., albatrosses, Southern Giant Petrel *Macronectes giganteus* and large petrels *Procellaria* spp.) had been reported in the early 2000s (Tuck *et al*., 2003; Woehler *et al*., 2001). While populations in the north of the CCAMLR area are still at risk, the reduction of seabird mortality has been significant in fisheries regulated by CCAMLR (Ramm, 2013).

Scientific research and monitoring have been intensive in the Southern Ocean for more than a century. One of the most noteworthy of these research programs was the Census of Antarctic Marine Life (CAML), a project framed in the Census of Marine Life program. Within the CAML framework and the International Polar Year 2007-2009, 19 research voyages were coordinated with researchers from over 30 nations (Miloslavich *et al*., 2016). These expeditions significantly advanced our understanding of Southern Ocean ecosystems and biodiversity (Brandt *et al*., 2007; Broyer and Koubbi, 2014) and also helped to identify and declare new areas as vulnerable marine ecosystems (Gutt *et al*., 2010). To manage the effects of fishing in both target and associated species, the CAMLR convention also established in 1989 the Ecosystem Monitoring Program (CEMP) to allow for the detection of changes in the ecosystem components and their attribution. CAMLR goals and CEMP are supported by a very strong community of practice (e.g., the Southern Ocean Observing System; SOOS). SOOS has proposed and is currently developing a set of ecosystem Essential Ocean Variables to be measured in a sustained and coordinated manner to assess changes in Southern Ocean diversity and ecosystems and its causes (Constable *et al*., 2016).

The Conservation for the Arctic Flora and Fauna (CAFF)

Background on CAFF is given in section S3.12. Here we assess progress towards its objectives. Research and monitoring have been carried out in the Arctic for more than a century, but given the size, remoteness, habitat complexity and technical challenges, baseline inventories of species in many areas are still lacking or incomplete, especially for the marine realm (Gradinger *et al*., 2010). This knowledge gap makes it very difficult to assess Arctic biodiversity patterns and trends over time (Archambault *et al*., 2010; CAFF, 2013; Lindal Jorgensen *et al*., 2016). However, with the Circumpolar Biodiversity Monitoring Program and the State of the Arctic Biodiversity reports, gaps and available data are being identified for the Arctic Focal Ecosystem Components (CAFF, 2017). The Arctic has undergone dramatic changes since the Holocene, driven mostly by climate fluctuations which have impoverished its biodiversity. At present, climate change is the most important driver of environmental change in terrestrial, freshwater and marine ecosystems, including the thinning of the ice pack (CAFF, 2017; Ims and Ehrich, 2013; Michel, 2013; Wrona and Reist, 2013). Other drivers causing changes and degradation of the Arctic ecosystems are ocean acidification, pollution, landscape disturbance, changes in currents, invasive species and exploitation of resources (CAFF, 2017). How these changes will affect biodiversity is poorly understood, but under future scenarios of climate change, Arctic habitats may be irrevocably lost (Michel, 2013). Food resources are being lost for many Arctic marine species; increasing numbers and diversity of southern species are moving into Arctic waters, and current trends indicate that the high Arctic marine species are under huge pressure. Species that depend on sea ice for reproduction, resting or foraging will experience range reductions. Arctic marine species and ecosystems are also undergoing pressure from changes in their physical, chemical and biological environment (CAFF, 2017). While there are few time series available that date back to the 1950s and 1960s, an analysis of the Arctic Species Trend Index data by decade indicated that the proportion of locations with decreasing populations has grown from 35% in 1950-1960 to 54% in 2000-2010 (Bohm *et al*., 2012; McRae *et al*., 2012). Awareness of the profound changes in the Arctic has also been improving thanks to the establishment of several Arctic Long-Term Ecological Research sites, especially since the late 1990s when more detailed and across ecosystem analyses was implemented (Soltwedel *et al*., 2016).

Several marine mammal species were historically hunted in the Arctic, with some overharvested such that populations were depleted (e.g., bowhead whale *Balaena mysticetus*) or driven extinct (e.g., Steller's sea cow *Hydrodamalis gigas*). Regulation of these activities has led to stabilization or recovery of some populations of some species (Jorgensen *et al*., 2016). The Circumpolar Biodiversity Monitoring Program has identified 32 Focal Ecosystem Components to use as indicators of ecosystem state. For marine mammals for example, an assessment of 84 stocks of 11 species indicated that eight are increasing, 14 are stable, four are decreasing, but for the remaining 53, trends are unknown. The most dramatic cases are for polar bear *Ursus maritimus*, for which seven out of 19 populations are declining, four are stable, and only one is increasing (Reid *et al*., 2013). Another example is the Cook Inlet beluga whale *Delphinapterus leucas* population, which declined in the 1990s and still remains Critically Endangered (Jorgensen *et al*., 2016). For terrestrial carnivores, trends vary among species, populations and regions, ranging from increases to local extirpation, while for herbivores, populations fluctuate through time, independently of human stressors (Reid *et al*., 2013). With regards to birds, most of the Arctic species are migratory and therefore their population trends are affected by drivers (e.g., food availability, habitat loss) across their migratory routes. Some migratory populations are known to have increased (e.g., many Nearctic and Western Palearctic waterfowl populations, especially geese), while others have decreased (e.g., in the Eastern Palearctic). For resident bird species, trends are poorly known (Ganter & Gaston, 2013). For most seabird populations, trends have been negative (Jorgensen *et al*., 2016) or are difficult to assess due to lack of information. Particularly for geese populations, it is suspected that those species with the poorest information are those with the greatest declines (CAFF, 2018). For amphibians and reptiles, there are no reports of declines, but data are very scarce (Kuzmin & Tessler, 2013). For freshwater fish species, about 28% are under threat (e.g., the five sturgeon species), while for marine species, population trends cannot be inferred due to the lack of data except for a few commercial species (Christiansen & Reist, 2013). Fisheries and bycatch are the main threats to marine fishes and occur mostly in the shelf areas connecting the Arctic to boreal regions of the Atlantic and Pacific Oceans (e.g., the Barents Sea and Bering Sea). It is expected that as the waters continue to warm, fishing activities will spread to previously unfished Arctic regions. For phytoplankton, zooplankton and benthic invertebrates, there is insufficient information to infer trends, but there are a few documented cases of the negative effects of anthropogenic activities on population size, abundance, growth and species distribution (Gradinger *et al*., 2010; Jorgensen *et al*., 2016). Overall, current monitoring is not sufficient to determine status and trends for most Focal Ecosystem Components (CAFF, 2017).

Protected areas within the CAFF boundary cover 20.2% of the Arctic's terrestrial area and 4.7% of the marine area, which is almost two and four times the terrestrial and marine areas protected in 1980 respectively. Combined, these areas and cover 3.7 million km^2 and 11.4% of the Arctic. The effectiveness of the management of these areas, and their levels of governance vary across countries. While this represents progress towards policy goals, these protected areas still do not represent all ecologically relevant ecosystems, cover all important sites for biodiversity, or meet other aspects of Aichi Target 11 within the Arctic region (Barry *et al*., 2017; CAFF & PAME, 2017).

3.5 CROSS-CUTTING SYNTHESIS OF TARGET ACHIEVEMENT

To identify broad patterns of progress towards the Aichi Biodiversity Targets and SDGs, we first identified thematic groups of Aichi Biodiversity Targets and SDG targets based on an assessment of the relationships between each target and the different components (nature and NCP) of the IPBES conceptual framework (see chapter 1). We then synthesized the patterns of progress presented in sections 3.2 (on Aichi Biodiversity Targets), 3.3 (on SDGs) and 3.4 (on other biodiversity agreements) for each of these themes. As most other agreements endorse the Aichi Biodiversity Targets (see sections 3.4 and S3.9), we assumed alignment of individual targets of these agreements with the Aichi Biodiversity Targets.

To identify themes that are cross-cutting across the Aichi Biodiversity Targets and SDGs, we carried out an expert-based classification exercise to assess the relationships between the targets/goals and two main elements of the IPBES conceptual framework (nature and NCP). For the SDGs, we scored both the goals and the most relevant targets within them. Scores rating the direction and the strength of the relationships were assigned in a Delphi process involving 31 authors of the IPBES global assessment and refined by a smaller core team of four experts. Based on these scores, nine broad thematic groups of targets and goals were identified **(Figure 3.16)**. These thematic groups (themes) identify cross-cutting commonalities that emerge across various multinational environmental agreements in terms of the IPBES conceptual framework. Each theme contains only the most dominant targets that are considered cross-cutting across the SDGs and Aichi Biodiversity Targets (derived from the scoring exercise). Other related targets are considered to complement the discussion relating to the theme. Progress in achieving targets within the themes is summarized in the following paragraphs. It is to be noted that we synthesize results of assessments on progress towards the Aichi Biodiversity Targets and other biodiversity agreements and on trends in nature and NCP relating to achieving

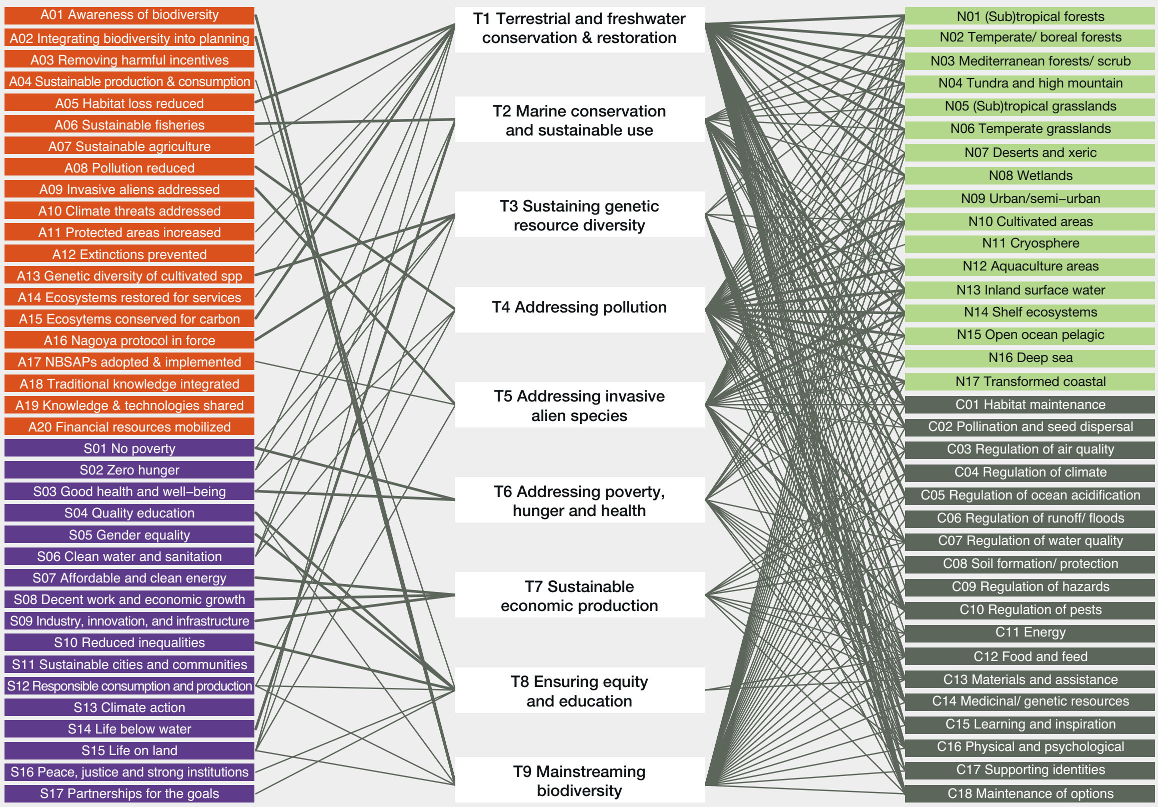


Figure 3 16 **Nine themes cutting across the Aichi Biodiversity Targets, SDGs and other related multilateral environmental agreements.**

These themes were defined through their relationships to targets of major environmental agreements (Aichi Biodiversity Targets, Sustainable Development Goals), and elements of the IPBES conceptual framework (nature and nature's contributions to people) in a cluster analysis exercise (see section S3.13). The thickness of the lines indicates a degree of association. Only targets significantly associated with each theme are shown.

the SDG targets. The term 'progress' is therefore used in a broad sense, encompassing trends related to the individual agreement goals/targets. Details of the expert-based scoring and the statistical analysis of the results are documented in S3.13, Figure S3.1, Table S3.9, Table S3.10, and Table S3.11 in the Supplementary Materials.

1. Terrestrial and freshwater conservation and restoration

This theme brings together goals and targets related to the conservation and restoration of terrestrial and freshwater ecosystems. It includes measures to conserve threatened species and actions to ensure the integrity of ecosystems. Apart from cross-cutting targets of Aichi Biodiversity Targets 5 (habitat loss, degradation & fragmentation reduced) and 15 (conservation and restoration of ecosystems for carbon) and SDG target 15.1 (freshwater ecosystem conservation), other targets associated with this theme include Aichi Biodiversity Targets 11 (protected areas etc.), 12 (extinctions prevented & threatened species conserved), 14 (ecosystems providing services restored and safeguarded), SDG target 6.6 (protect and restore water-related ecosystems), and several other targets from SDG 15 (e.g., 15.2, 15.3 and 15.5). Relevant targets and goals from other conventions such as the UNCCD, Ramsar Convention, CMS and the ITPGRFA also reinforce achieving conservation of terrestrial resources and ecosystems.

This group of targets receives considerable attention from policymakers, as most human activities happen on land, from agriculture to urbanization, among others. Several NCP, material goods and cultural contexts of nature are linked to ecosystems and resources on land including species, water and green spaces. Progress across relevant targets is varied. For instance, for some elements of some targets (such as protected area coverage) there has been good progress, while progress has been poor to moderate in others such as those relating to effective management and coverage of areas of importance for biodiversity, ensuring sustainable production and management systems in sectors such as agriculture and forestry, ensuring health, food and water security, reducing species declines, and building resilience of vulnerable populations (see sections 3.2,2, 3.2.3, 3.4.2, 3.4.3). This is reinforced by results from other relevant biodiversity related agreements such as the UNCCD, CITES, CMS, Ramsar Convention on Wetlands, and the IPPC (section 3.4). That said, better standards for phytosanitary measures in trade in biological resources and efforts to improve compliance with CITES measures are showing moderate progress. Some of the major drivers of land use change have been the impacts of urbanization and increasing consumption, which has resulted in high ecological footprints with increasing pressures on all resources.

Several of the targets do not have sufficient data to assess trends (e.g., reduction in disasters, access to green spaces). Moderate progress is reported in the achievement of targets towards conservation of natural and cultural heritage, which is also reflected in the progress towards the achievement of the goals of the Convention concerning the protection of the World Cultural and Natural Heritage (section 3.4).

Overall, more concerted and synchronized efforts are required to ensure that local actions can be implemented considering both policy goals and local priorities. This links also to raising awareness, building capacities of different actors in an inclusive and reflexive manner, and providing relevant incentives and disincentives to trigger appropriate action towards sustainable use and management of terrestrial ecosystems.

2. Marine conservation and sustainable use

This theme emphasizes the need for specific attention and actions relating to the oceans and marine ecosystems to ensure conservation and sustainable use of marine resources through actions including regulation of fisheries and appropriate incentives to ensure the health of marine ecosystems. The theme reaffirms the close linkages between human well-being and the health of the oceans. It is captured across the Aichi Biodiversity Targets (6 on sustainable fisheries) and SDGs (14 on life below land) and other conventions related to the oceans.

Progress and trends towards goals related to marine conservation and restoration vary from poor to moderate. Some significant steps have been made in the implementation of umbrella conventions such as the UN Convention on the Law of the Sea (UNCLOS), the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) and the United Nations Fish Stocks Agreement (UNFSA), but marine biodiversity and ecosystems continue to face multiple threats from human activities, including habitat loss, pollution, human disturbance, unsustainable and unregulated fisheries and climate change. Measures such as managing trade, expanding marine protected areas, and developing guidelines for no-fishing zones (through conventions such as CITES or reporting guidelines of FAO, the Convention on Biological Diversity (CBD) and the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) have had some positive effects. However, it has also been noted that focus is often paid to the conservation of certain marine species, which impedes conservation efforts of other species (see sections 3.2.2; 3.4.2 and **Boxes 3.1, 3.2**). The consequences of coastal and deep-sea fishery stock depletion and ecosystem degradation has had negative consequences for the well-being of IPLCs in terms of food security, spiritual and social integrity and livelihoods. Furthermore, despite the long associations and interactions between IPLCs and oceans, the knowledge and experience of IPLCs has largely remained untapped in designing conservation and management strategies (see sections 3.2.4; 3.3.3).

3. Sustaining genetic resource diversity

This theme focuses on the basic units of life that provide diversity to life forms and options for the future (whether as food, medicine, materials, etc) and on incentives to ensure this diversity is maintained. It is the specific focus of Aichi Biodiversity Targets 13 (genetic diversity of cultivated species and wild relatives) and 16 (Nagoya Protocol), and SDG targets 2.5 and 15.6 (on prioritising genetic diversity of crops and promoting fair and equitable benefit-sharing respectively), suggesting that human well-being is connected to ensuring existence and access to diverse germplasm. It also emphasises the importance of ensuring that accessing these resources and generating benefits are achieved with the full, informed participation of all stakeholders in a manner that can be considered equitable. Implementing the Nagoya Protocol requires acknowledging the merits of traditional knowledge and practices for management of biodiversity and ecosystems.

Insufficient progress is being made in safeguarding the genetic diversity of plants, animals and their wild relatives, which require, greater effort to document the patterns of this diversity, and greater participation of local actors such as IPLCs to actively conserve germplasm in the form of landraces or native cultivars (see 3.2.4 3.3.2; 3.3.3). Little progress is also reported in related targets to end illegal trade of protected species, although institutional efforts are being strengthened (section 3.3 and section 3.4.2). It is noteworthy that the trends towards achieving genetic diversity targets are mixed, with positive trends noted in some crops and negative for others and livestock diversity. Targets such as SDG 2.3 (double productivity and incomes of small-scale producers) will need to be carefully implemented in the light of potential negative impacts if the pathways chosen increase intensive agriculture and mono-cropping practices. Local experiences illustrate that given adequate support; it is possible to achieve these various targets (see section 3.2.3; 3.3.2).

There has been moderate progress in the achievement of targets related to access to genetic resources and equity in sharing benefits arising from their use (Aichi Target 13 and SDG target 15.6), which are directly linked to equity and fairness. It is pertinent that the major indicator used to track equity is the number of countries that have ratified the Nagoya Protocol. Although much progress has been reported on the Access and Benefit-Sharing Clearing-House Mechanism (ABSCH) on national implementation, including legislative measures and monetary and non-monetary benefit-sharing, specific indicators capturing such information are still to be developed and included in the assessment of progress towards the targets. The ITPGRFA also deals with accessing genetic resources and benefit-sharing for selected food and agricultural crops through a well-functioning system of exchange of plant genetic resources for food and agriculture (PGFRA) from *ex situ* collections to different users. Furthermore, benefit transfers to providers of resources is developing through a mix of donations and payments for access to germplasm collections (see S3.10).

4. Addressing pollution

This theme focuses on pollution, its relationship with nature, good quality of life and the regulatory functions of NCP. It focuses also on the need to reduce pollution for healthy lives through appropriate clean production. It is seen as an area to be addressed in other conventions such as the Ramsar Convention, IPPC and the UNCCD in order to address their specific objectives too.

Pollution is one of the most important drivers that affects ecosystem integrity, species populations and human well-being. Aichi Target 8 (reduce pollution) and SDGs 3.9 (reduce deaths and illnesses from pollution) 6.3 (improve water quality by reducing pollution) and 14.1 (reduce marine pollution of all kinds) specifically aim to tackle this issue. While the adverse effects of pollution are well understood, actions towards addressing various types of pollution (air, water, soil, ocean etc) through different interventions have resulted in poor to moderate progress and trends to achieving the targets. Assessment of trends are also impaired due to inadequate data (either globally or regionally) on the links between pollution and quality of life, (e.g., SDG 3). Overall, despite the availability of appropriate technologies and high levels of awareness of the problems of pollution to nature, NCP and human well-being, there has been insufficient progress towards these targets globally (see sections 3.2, 3.3 and **Figure 3.13**)

5. Addressing invasive alien species

This theme brings together targets (Aichi Target 9 on invasive alien species identified and addressed and SDG 15.8 on reducing the impacts of invasive alien species) that focus on restricting the spread and impacts of invasive alien species, which cause significant ecological, economic and social impacts in most regions (see also chapter 2.1 and 2.2). This theme is linked to other indirect drivers such as the movement of resources due to trade (legal and illegal) or migration, and hence progress to achieving associated goals and targets is reliant on progress in implementing measures related to these drivers. Specific targets to tackle invasive alien species are also included in other conventions such as the Ramsar Convention on Wetlands.

While encouraging progress has been made in implementing eradications of invasive alien species (at least on islands), with substantial benefits to native species, poor progress has been reported in the achievement of targets related to containing and reducing the spread and impact of invasive alien species, with countries reporting this to be one of the least achieved targets (section 3.3; 3.4). Little progress has also been reported on the integration of ILK into implementation, despite evidence from the ground of the benefits of such an approach (sections 3.2.3, 3.3.2. Overall, while there are local examples of good practices to ensure the integrity of ecosystems, determined efforts are needed to address various dimensions that impact ecosystem integrity.

6. Addressing poverty, hunger and health

This thematic group brings together three of the most critical well-being needs of people: sustained and sufficient income, food and nourishment and the ability to lead healthy lives. These emerge as a set of cross-cutting topics that are sought to be achieved explicitly in the SDGs (Goals 1, 2, 3) and also given importance within the Aichi Biodiversity Targets (Target 14), and further impacted by policies implemented through other MEAs including the Ramsar Convention, ITPGRFA and CITES. Achieving these different goals hinges on the availability and access to various material, regulating and non-material contributions from nature, and anthropogenic assets including technology, knowledge and institutions.

Most targets and goals in this theme are from the SDGs, and trends towards achieving them vary from negative to insufficient. Poverty, malnourishment and health security continue to be major challenges encountered especially by socially vulnerable populations, and this may relate to lack of rights to access and utilize resources and benefits from them (see also section 3.2.3). It has been observed that even while some quality of life parameters show improvement in the short term, indicators relating to the supporting elements from nature and NCP show declining trends, indicating unsustainable development pathways (see sections 3.3; 3.4).

7. Sustainable economic production

This theme captures good quality of life elements including targets to ensure decent work and economic growth, access to affordable and clean energy for these purposes and innovation for sustainable production activities, including infrastructure (SDGs 8, 7 and 9 respectively). These activities also act as drivers to the utilization of ecosystems, resources and how nature's contributions to people can be sustained.

For many SDGs, the pathways chosen to achieve the targets will have impacts (positive and negative) on nature and the sustainable provision of its contributions to people, with far-reaching impacts on other SDGs, particularly the case for Goals 7, 8, 9, 12. New approaches to achieve these goals are available that can have positive impacts (such as growing demand for 'green' products). Assessing progress towards this theme is also limited by availability of relevant information and appropriate indicators. While the targets are of high relevance to IPLCs, unsustainable resource extraction for various production uses has resulted in many conflicts, including over the production of biofuels, other energy and mining. Overall trends are negative in achieving the various targets related to this theme (see section 3.2.3).

8. Ensuring equity and education

This theme focuses attention on several of the less tangible good quality of life elements such as education on sustainable development, ensuring inclusive development, ensuring peace and justice, ensuring equitable access to basic necessities such as food and resources, measures such as reducing waste of resources, and building operational and supportive partnerships between different actors. Achieving various targets under these goals also has consequences for desirable actions needed to achieve goals related to sustainable economic production. These have been identified as necessary to address targets pertaining to various dimensions related to nature, nature's contributions to people and good quality of life.

Measuring progress towards this theme is generally constrained by availability of sufficiently developed indicators. Still, a general inadequacy in having participatory and inclusive approaches in planning and design for both conservation and development policies appears to have stymied efforts to address various issues related to their effective implementation. Overall, despite advances in technologies and the presence of multiple policies to address human well-being and sustainability, trends still appear negative towards achieving relevant targets on this theme, requiring more focused and inclusive actions are required if we are to reach these goals.

9. Mainstreaming biodiversity

This theme focuses on targets and goals on including biodiversity and ecosystems in planning processes and thereby integrating the values of biodiversity across sectors and decision-making. Goals and targets included are those relating to awareness of biodiversity, integration of biodiversity in planning and sustainable development actions. This is a recurrent theme in most other Conventions including Ramsar, CMS, UNCCD and others.

Progress in mainstreaming actions vary from medium to low. Certainly, efforts to generate more awareness about biodiversity and ecosystems to sustain life and human well-being are being strengthened (sections 3.2, 3.3). However, adoption into planning processes is still lagging, indicated by a general inadequacy in ensuring coherence between sectoral policies such as for instance ensuring that urban planning is aligned with availability of green spaces, human health, food security and diversity in a changing climate. Progress in other associated targets and goals that pertain to actions across various sectors of production, consumption, conservation of biological and cultural diversity, innovation, equitable partnerships, and financial support further accentuate that more efforts are required to achieve good progress in this theme.

3.6 REASONS FOR VARIATION IN PROGRESS TOWARDS POLICY GOALS AND TARGETS

As shown in the preceding sections, there is a high degree of variation in progress towards meeting the goals and targets of Aichi, SDGs and other Conventions. This variation occurs between targets (i.e. some targets have greater progress than others), as well as between regions (i.e. some regions show greater progress than others towards particular targets, although information on this was available only for a subset of indicators and Aichi Biodiversity Targets). A review of the literature shows that multiple factors contribute to variation in the achievement of goals and targets. These factors can be broadly categorized as follows:

Biophysical and socioeconomic conditions: The distribution of biodiversity, socioeconomic status and development trajectories vary substantially between countries. This variation has implications for the ability of countries to meet specific policy targets (Robinson *et al*., 2009). However, the relationships between biodiversity, development and conservation or sustainable use are not simple or linear, and are often impacted by historic development, legacy effects and cross-scale dynamics and feedbacks from other countries and regions (Raudsepp-Hearne *et al*., 2010).

Human, institutional and financial capacity: These capacities are critical to the overall ability of nations to develop and implement plans and actions to achieve any given goal or target (Nowell, 2012; Reeve, 2006). For example, an analysis of a global database of hundreds of marine protected areas (MPAs) showed that the ability of MPAs to protect biodiversity was not only a function of environmental factors (e.g., ocean conditions) or of aspects of the MPA itself (e.g., size or regulations), but also dependent on the MPA's human and financial capacity (Gill *et al*., 2017).

Norms and values: Rands *et al*. (2010) suggest that, in addition to resources, the will to achieve a goal is critical for its actual achievement. Unfortunately, this is often overlooked; policy responses to biodiversity loss often fail to establish the institutions, governance, and behaviours necessary for achieving the specific targets and objectives of Conventions (Geldmann *et al*., 2018; Rands *et al*., 2010). The concept and value of biodiversity is often articulated or measured differently between different groups of people or across different regions (Gotelli & Colwell, 2001). Consequently, goals or targets that can incorporate multiple perspectives on biodiversity and its benefits, or which take into account local values, are more likely to resonate with key local stakeholders and to receive greater attention and, as a result, they are more likely to be achieved (Anthamatten & Hazen, 2007; IPBES, 2015; Pascual *et al*., 2017).

Governance and institutions: Building on previous results showing that governance is an important predictor of biodiversity loss (Smith *et al*., 2003), deforestation rates (Umemiya *et al*., 2010), protected area effectiveness (Barnes *et al*., 2016) and poaching (Burn *et al*., 2011), a recent analysis found that the governance quality explained substantially more variation in investment in biodiversity conservation than did direct measures of wealth (Baynham-Herd *et al*., 2018).

The focus and formulation of the target: The goals and targets assessed link to nature in different and complex ways, and, due to the complex interrelationships in socio-ecological systems, are themselves also interconnected and interdependent (Nilsson *et al*., 2016). Certain types of goals and targets may, therefore, be easier (or harder) to achieve than others. Some, such as Aichi Target 12 (preventing extinctions), are highly dependent on achievement of other targets (such as Target 5 addressing habitat conversion, Targets 6 and 7 on sustainable production, Targets 8 and 9 on particular drivers such as invasive alien species and pollution, and Target 11 on protected areas; see section 3.2). A review of efforts in Canada to meet the Aichi Biodiversity Targets found that implemented responses tend to be associated with targets that have specified levels of ambition or that are more straightforward to achieve (e.g., knowledge capacity and awareness) (Hagerman & Pelai, 2016). By contrast, targets addressing equity, rights or policy reform were associated with fewer actions, presumably because of less effective target design combined with a lack of fit within existing institutional commitments (Hagerman & Pelai, 2016). Furthermore, it may be harder to meet goals and targets that require global collaboration than it is to meet those achieved primarily through local action (Mazor *et al*., 2018). A recent review of the Aichi Biodiversity Targets strongly suggested that the articulation and framing of the targets may influence their achievements (CBD 2018c). The study found that significantly greater progress has been made towards targets that are considered more measurable, realistic, unambiguous and scalable, and targets that best adhered to the principals of 'SMART' objectives (i.e., Specific, Measurable, Ambitious, Realistic and Time-bound) were those that contained explicitly defined deliverables (CBD, 2018c). This is consistent with previous assessments that suggested that the degree to which progress can be measured may impact progress (Butchart *et al*., 2016; Campagne, 2017; CBD 2018c; Kenny, 2015; Moldan *et al*., 2012; Tittensor *et al*., 2014). Lack of robust data (Wood *et al*., 2008), incomplete datasets, dependency on self-reporting and shortfalls in the human and financial capacity to generate, analyse and report on progress (Nowell, 2012) also hinder the ability to measure progress and may in turn therefore impede achievement of goals and targets.

We found no consistent regional patterns of variation in progress towards the Aichi Biodiversity Targets, with some regions achieving greater progress than others towards particular targets (section 3.2.3. For example, there appeared to be greater progress towards Aichi Target 19 (on improving and sharing biodiversity knowledge and technologies) in the Americas, but slower progress for Targets 5 (on loss of natural habitats) and 11 (on protected areas). However, data constraints meant that this assessment was based on a limited set of indicators and only a subset of Aichi Biodiversity Targets. Due to the size of IPBES regions, the mixed patterns of progress and the limited scale of the regional assessment conducted, no clear factors emerged as important in determining regional differences in progress. It is likely that multiple factors are relevant in national and regional contexts with implications for target achievement. Regional variation in progress towards other conventions, as well as in the impacts of trends in nature and NCP on progress to the SDGs, was not assessed owing to insufficient regionally disaggregated information and indicators.

Consistent differences in progress were more apparent between different goals and targets. There has been greater progress towards goals and targets related to policy responses and actions to conserve nature and use it more sustainably than towards goals and targets addressing the drivers of loss of nature and NCP. Consequently, there was generally poor progress towards Targets aiming to improve the state of nature and aspects of NCP (**Tables 3.8** and **3.9**; **Figures 3.7, 3.8, 3.19**). For example, there has been good progress on responses such as eradicating invasive alien species (at least on islands; Aichi Target 9), expanding protected areas (albeit with caveats about their location and effectiveness; Aichi Target 11), implementing the Nagoya Protocol (Aichi Target 16), developing NBSAPs (Aichi Target 17), implementing plans for sustainable urbanization and climate action (SDGs 11 and 13), and efforts to conserve and sustainably use ecosystems (SDGs 14 and 15), and sharing information and coordinating between MEAs (see sections 3.2, 3.3, 3.4). Despite this, indicators show that the drivers of biodiversity loss are increasing, and hence progress towards goals and targets to reduce these pressures has been generally poor. For example, freshwater, marine and urban pollution is increasing (Aichi Target 8, SDGs 6, 14 and 11), invasive alien species are increasingly having negative impacts (Aichi Target 9, SDGs 14 and 15), and drivers associated with unsustainable agriculture, aquaculture, forestry and fisheries are increasing pressures on nature and its ability to deliver NCP (Aichi Target 5, 6, 7, SDGs 12, 14, 15; sections 3.2 and 3.3).

As a result of the progress towards targets addressing drivers being insufficient, despite positive progress to targets addressing responses to biodiversity loss, progress to targets aiming to improve the state of biodiversity has been poor. For example, natural habitats continue to be lost, species' abundance is declining, and extinction risk trends are deteriorating (Aichi Biodiversity Targets 5 and 12, SDGs 14 and 15; sections 3.2 and 3.3). Trends in the magnitude of NCP are less well known, but four of five indicators used to assess progress towards Aichi Biodiversity Targets show significantly worsening trends (section 3.2). The NCP-dependent cluster of SDGs (1, 2, 3 and 11, addressing poverty, hunger, health and well-being, and sustainable cities) showed similarly negative impacts of declines in NCP (section 3.3).

This disconnect between progress in responses and increases in drivers of change in nature and NCP requires consideration. There is not a simple linear relationship, owing to several reasons. First, from a small set of counterfactual studies and other assessments (e.g., Geldmann *et al*., 2013; Hoffmann *et al*., 2010, 2015; Jones *et al*., 2016; Waldron *et al*., 2017), trends in drivers and the state of nature would be worse without the conservation responses that have been implemented (section 3.2). Second, the responses assessed are only a small set of sectorally limited responses out of many possible and necessary responses required to stem the drivers of loss in nature and NCP. For example, approaches to achieve several of the SDGs on climate, energy, economic growth, industry, and consumption and production (7, 8, 9, 12, 13) are likely to have a substantial impact on trends in drivers including pollution, habitat loss and degradation, invasive alien species, and on the state of nature and NCP, requiring more than just protected areas to prevent impacts (Maron *et al*., 2018). Third, many of the targets track responses at the planning or policy level, rather than the actual enforcement and implementation level, implying that the responses may be less effective than assessed at stemming drivers and loss of nature. For example, the extent of protected areas has grown considerably, but their effectiveness is often insufficient (e.g., Clark *et al*., 2013; Gill *et al*., 2017; Marine Conservation Institute, 2017; Schulze *et al*., 2018; section 3.2). Finally, there is the potential for mismatches (spatially, temporally and sectorally) between responses and drivers, made more complex by telecoupling—interactions between distant places—which are increasingly widespread and influential, and can lead to unexpected outcomes with profound implications for our ability to meet global goals for sustainability (Liu *et al*., 2013). Policy coherence across sectors and scales, at the heart of Agenda 2030 and the SDGs, will better account for different trade-offs between these interdependent goals and targets.

While there is a considerable body of literature on the potential explanations for variation in achieving goals in particular locations or achieving a particular goal in multiple regions, the existing literature is notably lacking in synthetic understanding of the reasons for variation. Improving understanding and evidence of these reasons for variation in progress towards goals would help achieve greater success in future.

3.7 IMPLICATIONS FOR DEVELOPMENT OF A NEW STRATEGIC PLAN ON BIODIVERSITY AND REVISED TARGETS

The Strategic Plan on Biodiversity 2011–2020, adopted under the CBD, proposed ambitious biodiversity-related targets to be achieved by 2020 (CBD, 2010a). Here we discuss implications for any follow up to the plan (proposed by CBD, 2016a) such as a revised version with new or revised targets. We based this on considerations from the challenge of assessing progress towards the existing Aichi Biodiversity Targets (section 3.2 above), as well as towards SDGs (section 3.3) and the goals of other Conventions related to nature and nature's contributions to people (section 3.4), and secondly based on the considerations of the progress achieved or lack thereof (drawing on these three sections plus the cross-cutting synthesis in section 3.5 and discussion of reasons for variation in progress in section 3.6). Additional considerations when setting revised targets include the need for suitable language and wording to engage stakeholders and inspire action, socio-economic transformations for sustainable consumption, transformative changes and governance (see below and chapter 6), and to illustrate the importance of tackling a particular issue in order to address biodiversity loss. However, these aspects have been rarely addressed in the literature to date. Finally, it may not be possible for a particular future target to take full account of all of the points below, but their consideration across the whole suite of targets will hopefully strengthen any future version of the strategic plan.

Future targets with clear, unambiguous, simple language, and quantitative elements are likely to be more effective. Some of the existing Aichi Biodiversity Targets are difficult to interpret because they have ambiguous wording, undefined terms that are open to alternative interpretations, unquantified elements with unclear definitions of the desired end point, unnecessary complexities, and redundant clauses (Butchart *et al*., 2016; CBD 2018c). Of the 20 Aichi Biodiversity Targets, 70% lack quantifiable elements (i.e., there is no clear threshold to be met for the target to be achieved) and 30% are overly complex or contain redundancies (Butchart *et al*., 2016). For example, Target 7 calls for areas under agriculture, aquaculture and forestry to be 'managed sustainably', without providing any quantification in relation to sustainability. This makes it more challenging to determine the necessary actions to achieve them, to coordinate these across Parties, and to assess progress towards achieving them (Butchart *et al*., 2016; CBD, 2018c; Maxwell *et al*., 2015; Stafford-Smith, 2014), although vague wording may make it easier to achieve consensus in some contexts (Maxwell *et al*., 2015). Using simple succinct language in targets, and providing explanations, definitions and caveats in background documents, guidance, and preambular text, would be beneficial (Butchart *et al*., 2016; CBD, 2018c). Quantification, however, will be only helpful if it focuses on the most appropriate metrics (see below in relation to protected area coverage).

Future targets that more explicitly account for aspects of nature or NCP relevant to good quality of life will be more effective at tracking the consequences of declines in nature and NCP for well-being, as well as better able to support future assessments of implications for SDG achievement. The assessment of SDG targets concluded that while nature and NCP were known to be important for goals related to education, equity, gender equality, and peace; a current lack of targets capturing these aspects of nature made an assessment of implications for these SDGs not currently possible. Clearer formulation of targets which capture the contributions of nature to these important development goals, will not only support improved assessments, but also foster new knowledge and evidence of these complex linkages. Similarly, the assessment of SDGs 1, 2, 3 on poverty, hunger and health respectively was limited to a few targets capturing the contributions of nature to these goals, however a wider set of contributions is known to exist but not currently assessed due to this gap.

Future targets may be more effective if they take greater account of socioeconomic and cultural contexts. Targets focused on equity, rights, or policy reform for better governance and sustainable economies (see chapter 6 section 6.4) appear to have resulted in fewer actions than other targets, mainly because of a lack of fit within existing institutional commitments (Hangerman & Pelai (2016), and perhaps because they are more difficult to achieve. Increasing consideration of values, drivers, and methods of valuation in the context of policies and decision-making when setting targets may also help to reduce lack of political cooperation, inadequate economic incentives, haphazard application of policies and measures, and inadequate involvement of civil society (Ehara *et al*., 2018; Hangerman & Pelai, 2016; Meine, 2013). For example, it has been argued that there is a need for frameworks and tools for understanding and acting upon the linkages between human rights, good governance and biodiversity (Ituarte-Lima *et al*., 2018). Targets may be easier to interpret if they are more explicit about the socioeconomic and cultural contexts that determine the pathways through which the outcome should be achieved, to avoid undesirable socioeconomic consequences (e.g., protected area expansion or establishment taking into account the impacts on IPLCs; Agrawal & Redford, 2009) or negative impacts on different cultures.

Future target setting will be more inclusive if it integrates insights from the conservation science community, social scientists, IPLCs, indigenous and local knowledge, and other stakeholders. For example, conservation scientists can help to establish ecologically sensible protected area targets and to identify clear and comparable performance metrics of ecological effectiveness (Watson *et al*., 2016a). However, to take into account governance issues and trade-offs between ecological, economic, and social goals, inputs and perspectives from social scientists, indigenous and local knowledge, and non-academic stakeholders from all regions are also needed (Balvanera *et al*., 2016; Bennett *et al*., 2015; Larigauderie *et al*., 2012; Martin-Lopez and Montes, 2015). Socioeconomic and cultural contexts are often not considered when targets or indicators are proposed. In particular, Hangerman & Pelai (2016) suggested that targets focused on equity, rights, or policy reform were associated with fewer actions mainly because of lack of fit within existing institutional commitments rather than because of a lack of effective target design. It is important to consider epistemological and ethical pluralism (instead of the predominant ethical monism of Western cultures) when discussing values, consumption patterns, and alternative economic models in the context of policies, decision-making and target setting (see section 6.4 of chapter 6).

Finally, it has been suggested that a future version of the strategic plan could consider highlighting fewer and more focused headline targets (including those focused explicitly on retention of biodiversity; Maron *et al*., 2018), alongside specific subsidiary targets capturing other elements. Such headline targets might highlight a set of specific actions for conservation of nature and NCP, e.g., ambitious, specific, quantified targets to reduce deforestation and wetland degradation, increase the sustainability of fisheries, minimize agricultural expansion, manage invasive alien species, increase the extent and effectiveness of protected areas (and their coverage of important sites for biodiversity), address ocean acidification, promote the recovery of threatened species, and increase financing, underpinned by more specific subsidiary targets covering other aspects of the existing Aichi Biodiversity Targets (Butchart *et al*., 2016; Maron *et al*., 2018). An alternative approach would be to retain and update all Aichi Biodiversity Targets, but focus on a subset such as those listed above for communications and publicity.

The failure to achieve some targets or particular elements of targets, alongside success in achieving other elements, also has implications for a new version of the strategic plan. Thus, targets that have not been achieved may require increased effort and/or new tactics, while the elements of targets that have been successfully achieved may require increased ambition and/or monitoring to detect and avoid potential regression. In this sense, time-bound targets could be considered as milestones in a process, rather than as final objectives. CBD (2018c) suggested that future targets should be ambitious but realistic, recognizing that ambition without realism can undermine confidence in the ability to deliver on targets, but equally that ambition also promotes and drives progress.

Future protected area targets that focus on enhancing coverage of important locations for biodiversity and strengthening management effectiveness may be more effective than simply setting a specific percentage of the terrestrial and marine environments to be conserved. In implementing Aichi Target 11, most focus has been on achieving the target percentages of terrestrial and marine area to be covered by protected areas (Barnes, 2015; Barnes *et al*., 2018; McOwen *et al*., 2016; Spalding *et al*., 2016; Thomas *et al*., 2014; Tittensor *et al*., 2014), at least partly owing to lack of explicit guidance on other aspects specified in target, for example on how to measure ecological representation, how to conserve through effective and equitable management, or how to define 'other effective area-based conservation measures' (OECMs). In particular, a focus on the area percentage may have distracted from the need to locate protected areas to cover effectively 'areas of particular importance for biodiversity' such as Key Biodiversity Areas (Butchart *et al*., 2012, 2014; Edgar *et al*., 2008; Juffe-Bignoli *et al*., 2014, 2016; Spalding *et al*., 2016; Tittensor *et al*., 2014), and to ensure that they are effectively managed (Barnes *et al*., 2015, 2018; Clark *et al*., 2013; Coad *et al*., 2015; Juffe-Bignoli *et al*., 2014, 2016b; Spalding *et al*., 2016; Watson *et al*., 2016b). While there have been calls for substantially higher area-based targets, tripling the current protected area network to cover 50% of the terrestrial surface (Baillie & Zhang, 2018; Dinerstein *et al*., 2017;Noss *et al*., 2012; Wilson, 2016; Wuerthner *et al*., 2015), these have also been criticized as being unfeasible and counter-effective in particular because they fail to consider the social impacts and the need to sustain protected areas socially and politically (Büscher *et al*., 2017). They may also deliver perverse outcomes (Barnes *et al*., 2018; Jones & De Santo, 2016), and if protected area expansion is concentrated in areas with low human influence, it is unlikely to conserve species diversity sufficiently (Pimm *et al*., 2018) or contribute to effective conservation outcomes (Magris & Pressey, 2018). While some efforts have been taken to operationalize other aspects of Target 11 (e.g., Faith *et al*., 2001; MacKinnon *et al*., 2015), any future protected area target may be more effective if it is structured to reduce the risk that areas with limited conservation value are protected at the expense of areas of biodiversity importance. In consequence, more effective nature conservation may be delivered by shifting the focus from efforts to achieve a pre-determined areal extent to efforts that achieve a specified biodiversity outcome (Barnes *et al*., 2018). This would require monitoring biodiversity outcomes and realistic targets and indicators taking account of financial and data constraints (Barnes *et al*., 2018). Alongside this, the terrestrial network of protected areas and OECMs will need to be substantially strengthened in order to conserve the most important sites for biodiversity while achieving ecological representation, improved effectiveness, better integration into the wider landscape and seascape, etc. (Butchart *et al*., 2015).

Future targets for marine protected areas may deliver better biodiversity benefits if they focus on management effectiveness in particular. Protection of marine areas is generally weak, even in wealthier nations (Boonzaier & Pauly, 2016; Shugart-Schmidt *et al*., 2015), with many marine protected areas being poorly enforced and ineffectively managed (Shugart-Schmidt *et al*., 2015). Management effectiveness may be enhanced through greater involvement of local stakeholders such as IPLCs (e.g., through the Locally Managed Marine Areas network; http://lmmanetwork.org/) and greater focus on key drivers such as pollution and unsustainable fisheries (see chapter 6). Increased consideration of the connectivity of marine protected areas is also needed (Lagabrielle *et al*., 2014; Toonen *et al*., 2013). In areas beyond national jurisdiction, future targets would focus on creating internationally recognized marine protected areas (Rochette *et al*., 2014). As in the terrestrial realm, a substantial scaling up of efforts, will be necessary to protect biodiversity, preserve ecosystem services, and achieve socioeconomic aims (O'Leary *et al*., 2016).

Future protected area targets may be more effective if they also explicitly address freshwater ecosystems and their processes, integrating nature and people, considering also the threats impacting them, and the actions needed to sustain them, including management strategies that consider connectivity, contextual vulnerability, and human and technical capacity (Juffe-Bignoli *et al*., 2016b).

A greater focus on protected area governance is important, including the implementation of participatory policies, improving institutional and community organization capacity, and consideration of self-regulatory management practices based on indigenous and local knowledge (Ramirez, 2016). Potential actions in this direction include: knowledge and capacity-building, valuation, improving policy frameworks, strengthening partnerships across sectors and engaging IPLCs (Dudley *et al*., 2015). Progress to date also suggests that understanding the expectations of all stakeholders can facilitate progress towards targets, and that equity issues between stakeholders can be explicitly considered (Hill *et al*., 2016). For example, for protected areas, participatory area management and spatial and temporal zoning can help to distribute benefits and costs equitably between stakeholders (Hill *et al*., 2016).

The implementation of future targets on conservation of species and sites could be more efficient through effective prioritization. Formal prioritization methods (which involve setting explicit objectives and incorporating the costs of actions, their probability of success, and the size of budget) allow cost-efficient implementation of actions to achieve targets (Visconti *et al*., 2015). For example, in the EU, focusing restoration efforts on habitats with unfavorable conservation status (as reported under the Habitats Directive) may provide the largest benefit for species and the delivery of NCP (Egoh *et al*., 2014). Many countries face the challenge of prioritizing with little capacity for biodiversity conservation and poor baseline data on most biological groups, requiring the development of better strategies for prioritizing based on changes in ecological, social and economic criteria (McGeoch *et al*., 2016) at the global, regional and local levels.

A new framework for biodiversity will be less effective if it does not explicitly address the implications of climate change for nature conservation. For example, many species, key biodiversity areas and protected areas will require adaptation plans to be developed and implemented, with actions coordinated across species' distributions and coherent strategies implemented across protected area and site networks (Hole *et al*., 2009). Potential unintended consequences of climate change mitigation efforts that may have negative impacts on biodiversity (e.g., displacement of food crop cultivation into natural areas as a consequence of biofuel expansion, or mortality of birds and bats from inappropriately sited wind-energy developments; Küppel *et al*., 2017; Oorschot *et al*., 2010; Schuster *et al*., 2015), need to be minimized. At the same time, the role of healthy ecosystems in helping people (particularly IPLCs) adapt to climate change ('ecosystem-based adaptation'; Munang *et al*., 2013), can be integrated into planning and policies.

Future targets may be more effective if they consider the availability of existing indicators and the feasibility of developing new ones. Close to the end of the period for achieving the Aichi Biodiversity Targets, some of them (Targets 15 and 18) still lack functional quantitative indicators entirely, while others lack indicators covering particular elements of the targets (**Table 3.3**; McOwen *et al*., 2016; Tittensor *et al*., 2014). In some cases, the paucity of indicators is because the targets are not particularly 'SMART' (specific, measurable, ambitious, realistic, and time-bound; CBD 2018c; Perrings *et al*., 2010). In a recent review, targets that scored higher on these characteristics were associated with greater progress (CBD 2018c). In some cases, although indicators may exist, their sufficiency and suitability for tracking progress are considered inadequate (Butchart *et al*., 2016; McOwen *et al*., 2016; Tittensor *et al*., 2014), e.g., owing to limited spatial, temporal or taxonomic coverage (Tittensor *et al*., 2014) and/or their alignment with the text of the target (McOwen *et al*., 2016; Tittensor *et al*., 2014). While existing or potential indicator availability is only one consideration when setting targets, without appropriate indicators, it is much more challenging to determine if progress has been made or if targets have been met (Butchart *et al*., 2016; CBD 2018c; McOwen *et al*., 2016; Tittensor *et al*., 2014).

Given the importance of adequate information and indicators for biodiversity based on robust datasets (Geijzendorffer *et al*., 2016), **sustained and augmented investment is needed to maintain, expand and improve knowledge products that underpin multiple indicators**, such as the *World Database on Protected Areas* (IUCN & UNEP-WCMC, 2017), the *World Database of Key Biodiversity Areas* (BirdLife International 2016b), IUCN Red Lists of threatened species and ecosystems (Brooks *et al*., 2015; Juffe-Bignoli *et al*., 2016a, Thomas *et al*., 2014) and the *Global Biodiversity Information Facility* (Jetz *et al*., 2012), alongside strengthened regional and global coordination and cooperation for data sharing and reporting (Knowles *et al*., 2015) and the development of new indicators to address key gaps.

A new version of the strategic plan is likely to be more effective if it gives greater emphasis to the trade-offs and synergies between targets. Efforts to achieve one particular target can contribute to achieving others (synergies) but may reduce the extent to which a different target may be achieved (trade-offs). For example, under Aichi Target 11, expansion of terrestrial protected area coverage could also contribute to reducing the loss of natural habitats (Target 5), reducing extinctions (Target 12), and maintaining carbon stocks (Target 15) (Di Marco *et al*., 2016b), but might have unintended consequences on good quality of life if people are displaced from new protected areas (Targets 14 and 18), especially if attention is not paid to the elements of the target relating to equitable management and integration into wider landscapes and seascapes. Similarly, different SDGs may have synergistic interactions or competing demands and critical trade-offs. Identifying these is an essential precursor to developing pathways for integrated and socially just governance processes (Mueller *et al*., 2017). For example, progressive changes in human consumption may improve biodiversity outcomes even in the absence of additional protection (Visconti *et al*., 2015). It will also be important to consider trade-offs related to the distribution of limited resources between multiple targets (i.e., expanding the use of natural resources to achieve economic development goals (Brunnschweiler, 2008). Identifying and securing synergies between targets, and minimizing trade-offs, would maintain options for co-benefits before they are reduced by increasing human impacts (Di Marco *et al*., 2016b). Evaluation of trade-offs is likely to vary depending on the criteria used, including in relation to social equity, models of economic growth, justice and fairness as well as biodiversity conservation (see chapter 6).

Trade-offs related to the distribution of limited resources between multiple targets is also an important point to be considered. Currently, most nations around the world are expanding the use of natural resources to achieve liberal economic development goals (Brunnschweiler, 2008; but see section 6.4, chapter 6). Consequently, rates of anthropogenic habitat conversion are rising in conjunction with biodiversity loss (Bianchi & Haig, 2013; Dirzo *et al*., 2014; Hansen *et al*., 2013; Watson *et al*., 2016a), while financial resources for conservation are limited, requiring effective prioritization of resources for actions addressing different and multiple targets (e.g., Polak *et al*., 2016; Venter *et al*., 2014). Finally, trade-offs may occur between different goals across spatial scales (i.e., the effects of the trade-off are felt locally or at a distant location) and temporal scales (i.e., the effects take place relatively rapidly or slowly) and these could also be considered and made explicit (Green *et al*., 2018; McShane *et al*., 2011; Rodríguez *et al*., 2006; see chapter 6).

Given that IPLCs manage or have tenure rights over a quarter of the world's land surface, an area that intersects with c.40% of all terrestrial protected areas and ecologically intact landscapes (Garnett *et al*., 2018), a revised strategic plan on biodiversity may be strengthened by taking account explicitly of the contribution of IPLCs to achieving and monitoring biodiversity goals and targets at local, national and international levels, integrating the importance of formal recognition of customary rights under national law (e.g., appropriate recognition of Indigenous and Community Conserved Areas and sacred sites, respect of free, prior and informed consent etc.), and recognizing the need to disaggregate indicators to quantify the contributions and impacts on IPLCs (Bennett *et al*., 2015; Hagerman & Pelai, 2016). Related to this, 'other effective area-based conservation measures' (as referred to in Aichi Target 12) have been argued to be essential for meeting more ambitious targets for conserving biodiversity in future (Dudley *et al*., 2018).

Maron *et al*. (2018) argue that future targets need to be explicit about the state of nature that meeting them is intended to achieve, noting that unquantified or rate-based targets can lead to unanticipated and undesirable outcomes. They propose the development of a series of area-based, quality-specific 'retention' targets to ensure adequate provision of key ecosystem services as well as biodiversity conservation.

Finally, Mace *et al*. (2018) suggested that tracking progress towards future biodiversity targets should focus on three aspects: near-future losses of species (i.e. extinctions, e.g., using the Red List Index), trends in the abundance of wild species (e.g., using population-level indicators such as the Living Planet Index) and changes in terrestrial biotic integrity (e.g., using the Biodiversity Intactness Index), although improved representativeness, integration and data coverage are needed for indicators for all three aspects.

3.8 KNOWLEDGE GAPS AND NEEDS FOR RESEARCH AND CAPACITY-BUILDING

There are clear gaps in available knowledge that have limited our ability to assess progress towards the Aichi Biodiversity Targets, Sustainable Development Goals, and the targets of other biodiversity-related conventions. Despite these limitations, we have enough information to recognize that biodiversity is declining due to complex, integrated social, economic and political factors (see chapter 6), and that actions are needed at the global, regional and local level to meet agreed policy objectives for sustainable development.

For our quantitative analysis of indicators to assess progress against the Aichi Biodiversity Targets, many potential indicators could not be included because they are available only for particular regions or have time series that are too short. The indicators that were included vary in their geographical and/or taxonomic coverage, as well as the degree to which they are aligned with targets, leading to variable levels of coverage (**Tables 3.3,** S3.1; Tittensor, *et al*., 2014). Existing indicators based on species' data are biased to better known groups, and underrepresent invertebrates, plants, fungi and micro-organisms. Among drivers of biodiversity loss, information is particularly poor for unsustainable exploitation e.g., spatial patterns in the intensity of hunting, trapping, and harvesting of terrestrial wild plants (Joppa *et al*., 2016). For 19 elements of 13 Aichi Biodiversity Targets, representing 35% of the elements and 65% of the targets, indicator datasets suitable for extrapolation were unavailable (e.g., relating to harmful subsidies for Target 3, and sustainability of management of areas under aquaculture for Target 7). Targets 15 (ecosystem resilience and contribution of biodiversity to carbon stocks) and 18 (integration of traditional knowledge and effective participation of indigenous and local communities) lack any suitable indicators that could be extrapolated, and hence progress on these Targets could not be assessed on the basis of indicator extrapolations. For Target 15, and elements of Targets 6 (on sustainable fisheries) and 14 (on ecosystem services), the lack of both quantitative indicators and qualitative information means that no assessment of progress was possible **(Figure 3.6)**. For Target 11 (site-based conservation and delivery of ecosystem services and equitable benefits from protected areas) there is insufficient information on trends in management effectiveness of protected areas, and inadequate quantitative information on the contribution of 'other effective area-based conservation measures' to meeting the target. For Target 12 (preventing extinctions), there is a lack of information (particularly on trends) for extinction risk of invertebrates and plants, and for trends in population abundance for species in tropical regions as well. There are gaps in our understanding of the relationship between indicators and the underlying system functions/properties that they measure. There are also particularly few indicators relating to nature's contributions to people (**Table 3.3**; **Figure 3.5**; Tittensor *et al*., 2014). The sufficiency of indicators for the Aichi Biodiversity Targets (judged in relation to their alignment, temporal relevance and spatial scale) is lowest for Strategic Goal E (on enhancing implementation through participatory planning, knowledge management and capacity-building) (McCowen *et al*., 2016).

New indicators for such aspects will need to be developed for assessing progress under a post-2020 global biodiversity framework (CBD 2018d), and this will require resourcing (McOwen *et al*., 2016 Tittensor *et al*., 2014), along with continued updating of the existing indicators, most of which lack any sustained core funding (Juffe-Bignoli *et al*., 2016a, McOwen *et al*., 2016). Many of the existing indicators cannot be disaggregated to show trends in relation to indigenous and local people (leading to calls for including an 'indigenous qualifier' in data collection and SDG indicator development, in order to highlight the inequalities that Indigenous Peoples face across all SDGs (AIPP *et al*., 2015).

A new synthesis of the high-level messages and key findings from different biodiversity-related assessments may be helpful in developing and implementing new targets and indicators for a post-2020 global biodiversity framework (CBD 2018d). New data collection and sharing platforms, and support and capacity-building for data mobilization analysis is needed, particularly for developing nations (Tittensor *et al*., 2014) and non-western data sources (Meyer *et al*., 2015). Scaled-up *in situ* monitoring of biodiversity state, drivers and conservation responses is urgently needed to address the various gaps, particularly in tropical regions (Stephenson *et al*., 2017), and encompassing community and citizen science initiatives (Latombe *et al*., 2017). Appropriate national systems and data platforms for coordinating the collection and dissemination of monitoring data (e.g., 'clearing house mechanisms') would help to address this need, while capacity-building is needed in relation to data collection and analysis. While indicators are probably the most useful and best tool to assess progress, it is unlikely that all of the indicators needed will ever be available. Gaps can also be filled with other sources of information such as published studies and case studies (see sections 3.2, 3.3), or national reports from countries (e.g., CBD National reports) that may help measure progress towards achieving targets.

Other knowledge gaps limit the effectiveness of attempts to formulate and/or implement appropriate policies and responses. In particular, it would useful to review the effectiveness of further policy options, interventions, resource mobilization and the successful use of funding when implementing targets or developing new indicators (CBD 2018d). There is a lack of information on the effectiveness of different area-based conservation mechanisms (protected areas, community reserves, sacred sites etc.), restoration methodologies and indicators to assess progress, and a number of key threats (e.g., from unsustainable exploitation) lack adequate global spatial datasets (Joppa *et al*., 2016). Inadequate monitoring has limited the ability to adapt and adjust policies and their implementation to enhance their effectiveness and to share lessons.

For some of the SDGs, (e.g., Goals 1 and 3), the relationships between nature and achievement of these goals are not well understood, as they are complex, nonlinear, dynamic, context-specific and heavily affected by other anthropogenic mediating factors such as access, policies, governance contexts (see section 6.2), the dominant economic model (see section 6.4 of chapter 6), and demographic factors. Generally, the provision of ecosystem services is widely assumed to contribute to poverty alleviation, particularly in rural areas of developing countries. However, the means by which these contributions are achieved remains unclear (Suich *et al*., 2015; see section 6.3 of chapter 6). There is good evidence on the role that nature plays in supporting the well-being of people, but far less evidence on how (and whether) nature can help people move out of poverty and what changes in nature mean for pathways out of poverty.

Marine biodiversity and ecosystem knowledge vary considerably in quality and extent across geographic regions, habitats, depth and taxonomic groups. It is estimated that 98.7% of the ocean is still largely under sampled, meaning that we lack even the most basic knowledge needed for effective management (Appeltans *et al*., 2016; Figure 3.24). While coastal shelves and slopes in developed nations (e.g., the North Atlantic) are better known (Rice *et al*., 2016), even for these, knowledge is patchy both at temporal and spatial scales. Sampling efforts have been relatively high along coastal ecosystems but are still quite low in the open ocean (>2,000 km from land) even if they have intensified in the last decades (Appeltans *et al*., 2016). Some regions have received considerable attention, but habitat complexity and logistical challenges mean that knowledge is fragmented, and some areas are very poorly known (Alder *et al*., 2016; Appeltans *et al*., 2016; Lindal Jorgensen *et al*., 2016; Miloslavich *et al*., 2016; Ruwa & Rice, 2016). Knowledge of the sea below 1,000 m depth (i.e. almost 99% of the ocean volume), is very limited as this environment is significantly under sampled. A global strategy to assess deep sea ecosystems in a coordinated manner has been recently initiated in anticipation of potentially intensive exploitation of deep-sea resources (Johnson *et al*., 2016).

The best assessed marine species groups are commercial and top predator fish stocks (Campana *et al*., 2016; FAO, 2016; Hazin *et al*., 2016; Pauly & Lam, 2016; Restrepo *et al*., 2016), marine mammals (mainly focused on iconic or threatened species) (Rodrigues *et al*., 2014; Smith *et al*., 2016), seabirds (Croxall *et al*., 2012; Lascelles *et al*., 2016), turtles (Wallace *et al*., 2016), and plankton (Batten *et al*., 2016; Edwards *et al*., 2012), and coastal ecosystems such as coral reefs (Wilkinson *et al*., 2016). However, even within these, few have long-term time series data as, for example, the Continuous Plankton Recorder (80+ years) or the Great Barrier Reef Monitoring Program (20+ years). Only 4% of the 230,000 described marine species have been assessed for the IUCN Red List (IUCN, 2017). Of these, 29% are classified as Data Deficient, and 17% are threatened or extinct, many of which occur in regions of high biodiversity but that are poorly known (Webb & Mindel, 2015). As many of these high-biodiversity regions are also highly threatened by overfishing, habitat loss, pollution, invasive species and the impacts of climate change (Costello *et al*., 2010), it is likely that the number of threatened species will increase as assessments and knowledge of these areas improves (Appeltans *et al*., 2016). Species distributional information is particularly scarce at greater depths **(Figure S3.5)**. All of these knowledge gaps hinder development of effective ecosystem-based management and governance in the marine environment.

Most existing studies on the links between nature and development have focused at an aggregate scale, often only on quantifiable aspects; e.g., income or provisioning services rather than capturing the multidimensional nature of development and nature. More focus has been put on the observation of correlations or relationships, and less on the mechanisms of the links (Roe *et al*., 2014; Suich *et al*., 2015). Thus, most studies are not able to clarify which groups of people benefit (or not) from nature, whether the poor are among these beneficiaries, and which aspects of quality of life are affected by which aspects of nature. Achieving the SDGs will have significant implications for nature (e.g., Goals 7, 8, 9, 11, 12). Choices about how these goals are achieved will have very different consequences for nature, but significant knowledge gaps remain in understanding the positive and negative relationships that nature and its contributions to people may have in achieving targets and vice versa.

Finally, improved information is needed on the role of IPLCs in achieving the Aichi Biodiversity Targets and SDGs, because they hold significant knowledge on the links between nature, sustainable development and quality of life (e.g., Circumpolar Inuit Declaration; Gadamus *et al*., 2015; Ituarte-Lima *et al*., 2018; Singh *et al*., 2018). In addition, capacity-building can help to increase the participation and engagement of IPLCs in sustainable development planning and decision-making at all levels because biodiversity conservation in many locations is under their customary practices or land tenure. Customary institutions, such as local councils, can take the initiative in the recognition, implementation and enforcement of customary laws. However, failure to do so may end up in undermining these laws and result in failure in harnessing all the benefits that may ensue from their implementation.

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Chapter **4.**

PLAUSIBLE FUTURES OF NATURE, ITS CONTRIBUTIONS TO PEOPLE AND THEIR GOOD QUALITY OF LIFE

IPBES GLOBAL ASSESSMENT REPORT ON BIODIVERSITY AND ECOSYSTEM SERVICES
CHAPTER 4. PLAUSIBLE FUTURES OF NATURE, ITS CONTRIBUTIONS TO PEOPLE AND THEIR GOOD QUALITY OF LIFE

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CHAPTER 4

PLAUSIBLE FUTURES OF NATURE, ITS CONTRIBUTIONS TO PEOPLE AND THEIR GOOD QUALITY OF LIFE

EXECUTIVE SUMMARY

Chapter 4 focuses on scenarios and models that explore the impacts of a wide range of plausible future changes in social, economic and institutional drivers on nature, nature's contributions to people (NCP) and good quality of life. The chapter's assessment concentrates on studies published since 2008 that cover large regional to global spatial scales and time periods from the present to 2050, and up to 2100. This framing of the assessment means that this chapter is best suited to help setting the agendas for decision-making at national to international levels by identifying future challenges and providing a compelling case for action. Chapter 4 provides new insights compared to previous assessments by including the most recent scenarios and models, by examining a broad range of global change drivers and their interactions, and by highlighting the impacts on a wide range of indicators of nature, nature's contributions to people and good quality of life. Where possible, results are also interpreted in view of their implications for achieving the Aichi Biodiversity Targets and the Sustainable Development Goals.

This chapter endeavours to provide a balanced perspective on drivers of change and their impacts, but the strong bias in the scenario literature towards climate change impacts on nature limits the scope to which the chapter can provide a comprehensive vision of plausible futures to decision makers. Climate change has been studied far more extensively than other drivers (such as land use change, pollution, use and extraction of natural resources, and invasive alien species), and studies of interactions between drivers, especially more than two drivers, are relatively rare *(well established)* {4.2.1, 4.2.2, 4.2.3, 4.2.4}. Terrestrial systems are studied more extensively than marine systems, with a paucity of studies of freshwater systems (*well established*) {4.2.1.1}. Impacts on biodiversity and ecosystem function have been the focus of much more attention than nature's contributions or good quality of life (78%, 16% and 5% of literature reviewed, respectively; (*well established*) {A1.1}. Among nature's contributions to people, material (such as food production) and regulating contributions (such as carbon dioxide removal from the atmosphere into ecosystems) are more studied than non-material contributions in relation to scenarios (*well established*) {4.3.1}.

The large majority of the studies covered in this chapter is based on scenarios developed in support of climate change assessments (93% of literature reviewed; {4.1.3}, the most recent of which are the Representative greenhouse gas Concentration Pathways (RCPs) and their associated Shared Socio-economic Pathways (SSPs). This has the benefit of providing strong coherence with climate assessments but results in biases in terms of drivers of change and socio-economic processes included in the scenarios. For example, only few of the scenarios assessed in this chapter explore mechanisms leading to social or ecological regime shifts {4.5}. In addition, most scenarios do not explicitly take into account different worldviews and values associated with many non-material nature's contributions to people and, in general, were not designed to address a wide range of Sustainable Development Goals {4.5, Chapter 5}. Nonetheless, this chapter recognizes that the different scenario archetypes hold inherently different worldviews and values that ultimately drive the scenario outcomes {4.1}. Participatory scenarios are one means of including a richer range of processes and values explored, but it is difficult to extrapolate from the local scale of most participatory scenarios to the large regional and global spatial scales that are the focus of this chapter {4.4.2, 4.7}.

1 **Significant changes at all biodiversity levels – from genetic diversity to biomes – are expected to continue under future global changes. Despite projections of some local increases in species richness and ecosystem productivity, the overall effect of global changes on biodiversity is projected to be negative (*well established*). Interactions within and between biodiversity levels can significantly influence future biodiversity responses to global changes (*established but incomplete*).** A substantial fraction of wild species is simulated to be at risk of extinction during the 21st century due to climate change, land use, natural

resource extraction and impact of other direct drivers (*well established*) {4.2.1, 4.2.2, 4.2.3, 4.2.4}. Loss in intraspecific genetic diversity is expected due to the projected decrease in species population sizes and spatial range shifts. Genetic loss should be recognized as a serious threat to future potential for adapting to global change (*established but incomplete*) {4.2.1.2, 4.2.1.3}. Expected species range shifts, local species extinctions, changes in species abundances will lead to disruptions of species relations including disturbance of trophic webs, plant-pollinator and other mutualistic relations (*well established*) {4.2.2, 4.2.3, 4.2.4}, that can cascade through the entire ecosystem. Novel (no-analogue) communities, where species will co-occur in historically unknown combinations, are expected to emerge (*established but incomplete)* {4.2.1.2, 4.2.4.1}. As a consequence, new approaches to conservation are warranted that are designed to adapt to rapid changes in species composition and ensuing conservation challenges. Intraspecific diversity and interactions between different biodiversity levels need to be represented in global models and scenarios to improve future projections of nature {4.2.1.2, 4.2.1.3}.

2 **In marine ecosystems, most scenarios and models point towards a global decrease in ocean production and biodiversity, but the level of impact can vary widely, depending on the drivers, scenarios, and regions considered (*well established*).** All anthropogenic greenhouse gas emission scenarios result in a global increase in sea temperature, ocean acidification, deoxygenation and sea level rise (*well established*) {4.2.2.1}. By the end of the century, these environmental changes are projected to decrease net primary production (by ca. -3.5% under the low greenhouse gas emissions scenario, RCP2.6 and up to -9% in the very high emissions scenario, RCP8.5), and secondary production up to fish (by -3% to -23% under RCP2.6 and RCP8.5, respectively), as well as top predator biomass (*established but incomplete*) {4.2.2.2.1}. Fish populations and catch potential are projected to move poleward due to ocean warming (*well established*) with a mean latitudinal range shift of 15.5 km to 25.6 km per decade to 2050 (under RCP2.6 and RCP8.5, respectively) (*inconclusive*), leading to high extirpation rates of biomass and local species extinctions in the tropics (*well established*) {4.2.2.2.1}. The rapid rate at which sea ice is projected to retreat in polar seas, and the enhanced ocean acidification, imply major changes to be expected in the future for biodiversity and ecosystem function in the Arctic and Southern oceans (*well established*) {4.2.2.2.4}. All components of the food webs will potentially be impacted, from phytoplankton to top predators, and from pelagic to benthic species (*established but incomplete*).

3 **Relative to climate change impacts, published scenarios project that the choice of fisheries management and market regulation measures can have the strongest impacts on the future status of marine fish populations** *(well established)* {4.2.2.3}. In the face of continuous growth of human population that is projected to reach 9.8 billion (± ca. 0.4 billion) people in 2050 combined with rising incomes, the demand for food fish will likely increase (*well established*). Business-as-usual fisheries exploitation is foreseen to increase the proportion of overexploited and collapsed species (*well established*), as well as species impacted by bycatch {4.2.2.3}. Adaptive fisheries management that responds to climate induced changes of fish biomass and spatial distribution could offset the detrimental impacts of climate change on fish biomass and catch in most RCPs (but RCP8.5) (*inconclusive*) {4.2.2.3}.

4 **For marine shelf ecosystems, additional future threats include extreme climatic events, sea level rise and coastal development** which are foreseen to cause increased pollution and species overexploitation but also fragmentation and loss of habitats that directly impact the dynamics of marine biodiversity (*well established*) {4.2.2.2.2, 4.2.2.3}. These impacts could potentially feedback to the climate as coastal wetlands play a major role in carbon burial and sequestration globally (*well established)* {4.2.2.2.2}. In coastal waters, increasing nutrient loads and pollution in combination with sea warming are expected to stimulate eutrophication and increase the extent of oxygen minimum zones with potential detrimental effects on living organisms (*well established*) {4.2.2.3}. Coral reefs are projected to undergo more frequent extreme warming events, with less recovery time in between, declining by a further 70-90% at global warming of 1.5°C, and by more than 99% at 2°C causing massive bleaching episodes with high mortality rates (*well established*) {4.2.2.2.2}.

5 **Concerns about rapidly increasing plastic pollution now match or exceed those for other persistent organic pollutants**. If current production and waste management trends continue, about 12,000 Mt (million tons) of plastic waste will accumulate in the environment by 2050, especially in the ocean which acts as a sink (*established but incomplete*). The harmful effects of plastics have been evidenced at all levels of marine food webs from plankton to top predators but are not yet projected into the future {4.2.2.4.1}.

6 **In freshwater ecosystems, all scenarios and models point towards a decrease in freshwater biodiversity and substantial changes in ecosystems state and functioning, especially in tropical regions (*well established*).** Freshwater ecosystems cover only 0.8% of the world surface area but host almost 8% of the world's species described, making a high contribution to global biodiversity. Given that all scenarios are based on continued growth of human population density until 2050, impacts due to combined anthropogenic drivers on freshwater biodiversity and ecosystems are projected to

increase worldwide, and to be strongest in tropical regions where human population growth and biodiversity are concentrated (*well established*) {4.2.3}. Increases in land area used for urbanization, mining, cropland and intensification of agriculture are projected to boost the risk of pollution and eutrophication of waters, leading to extirpation of local populations, changes in community structure and stability (e.g. algal blooms) (*well established*) {4.2.3.3}, and establishment and spread of pathogens (*established but incomplete*) {4.2.3.3}. Under all scenarios, habitat fragmentation (e.g., damming of rivers) and exploitation are projected to increase the risk of species extinction with potential effects on food web dynamics, especially in tropical regions (*well established*) {4.2.3.4, 4.2.3.6}. These impacts on freshwater flows, biodiversity and ecosystems will likely be exacerbated by climate change, especially under moderate (RCP4.5) and high emissions (RCP6.0, RCP8.5): higher temperatures are projected to generate local population extinctions especially for cold-water adapted species, and species extinctions in semi-arid and Mediterranean regions, since the area extent of these climatic regions will shrink due to projected decrease in precipitation (increase of estimated extinction rates by ca. 18 times in 2090 under the SRES A2 scenario, compared with natural extinction rates without human influence) (*inconclusive*) {4.2.3.2}.

7 In terrestrial ecosystems, scenarios and models point towards a continued decline in global terrestrial biodiversity and regionally highly variable changes in ecosystem state and functioning (*well established*). Land-use change, and invasive alien species will continue to cause biodiversity loss across the globe in the future, with climate change rapidly emerging as an additional driver of loss that is increasing over the coming decades in relative importance across all scenarios (*well established*) {4.2.4}. Although large uncertainties exist regarding the exact magnitude of loss, it is well established that increasing global warming will accelerate species loss {4.2.4}. Already for relatively minor global warming, biodiversity indices are projected to decline (*established but incomplete*) {4.2.4}. Extinction risks are projected to vary between regions from 5% to nearly 25%, depending on whether a region harbours endemic species with small ranges or is projected to experience climate very different from today (*inconclusive*). Substantial climate change driven shifts of biome boundaries, in particular in boreal and sub-arctic regions, and (semi)arid environments are projected for the next decades; warmer and drier climate will reduce productivity (*well established*) {4.2.4.1}. In contrast, rising atmospheric CO_2 concentrations can be beneficial for net primary productivity of ecosystems, and is expected to enhance woody vegetation cover especially in semi-arid regions (*established but incomplete*) {4.2.4.1}. The combined impacts of CO_2 and climate change on biodiversity and ecosystems remain (*unresolved*) {4.2.4.1}.

8 The relative impacts of climate change versus land-use change on biodiversity and ecosystems are context-specific and vary between scenarios, regions, and indicators of biodiversity and ecosystem functioning (*well established*) {4.2.4.2, 4.2.4.3}. Land-use change pressures differ between scenarios, but managed land area continues to increase, with exception of some scenarios exploring sustainability trajectories. Scenarios of large-scale, land-based climate change mitigation rely on large increases of bioenergy crop area or large reforestation or afforestation with potentially detrimental consequences for biodiversity and some ecosystem functioning *(well established)* {4.2.4.2, 4.2.4.3, 4.5.2}. Interactions of land-cover change and future climate change enhance the negative impacts on biodiversity and affect multiple ecosystem functions (*established but incomplete*) {4.2.4.2, 4.2.4.3}. Pressure on biodiversity and ecosystem function from other drivers such as biological invasions will likely be accentuated at global scale, as trade between climatically and environmentally similar regions are projected to increase, and habitats continue to be disturbed (*established but incomplete)*. Overall, the small number of regional to global scale scenario studies that assess pollution or invasive alien species' impacts on nature precludes a robust assessment {4.2.4.4, 4.2.4.5}.

9 Many scenarios project increases in material nature's contributions to people, which are generally accompanied by decreases in regulating and non-material contributions (*established but incomplete*) {3.1, 3.2}. The simulated trade-offs between material vs. regulating and non-material ecosystem services are especially pronounced in scenarios with strong human population growth and per capita consumption (*established but incomplete*) {4.3.4, 4.2.2.3.1, 4.2.4}. Assumptions about population growth and increase in per capita consumption are projected to lead to rising demand for material services, especially food, materials and bioenergy, and are projected to reduce regulating contributions such as provision of clean water, pollination, or ecosystem carbon storage (*well established*) {4.3.2, 4.3.3, 4.5.3, 4.2.2.4, 4.2.2.5, 4.2.3, 4.2.4}. In the long term, substantial decreases in regulating contributions may have detrimental effects on material contributions, for example climate change impacts on all systems will be increased if climate regulation by forests or oceans is weakened (*well established*). The future magnitude of these cascading effects has yet to be determined *(inconclusive). This is because* most scenarios and models do not consider fully the interactions between multiple drivers and multiple ecosystem impacts, and as a consequence cannot quantify important feedbacks {4.3.3, 4.3.4, 4.5.1, 4.5.4}.

10 Scenarios examining trends in nature and nature's contributions to people show significant regional variation (*well established*). The

interconnectedness of the world regions emphasizes the need for decision-making on ocean, freshwater and land management to be informed by considerations of regional trade-offs among nature's contributions to people (*well established*). Future scenarios show that many regions will experience a general decrease of biodiversity and many regulating and non-material ecosystem services, but others will see increases (*well established*) {4.2.2, 4.2.4, 4.3.3}. The degree to which regions differ regarding impacts of global environmental changes depends on the underlying socio-economic scenarios, with climate change being an additional driver (*established but incomplete*) {4.1, 4.2, 4.3}. Scenarios of a world with regional political- and trade-barriers (Regional Competition Scenario) tend to result in the greatest divergence across regions, scenarios that emphasize liberal financial markets (economic optimism and reformed market scenarios) in intermediate levels of disparity, while scenarios that encapsulate aspects of sustainable development (Regional Sustainability and Global Sustainability scenarios) result in more modest differences between regions (*established but incomplete*) {4.3.3, 4.2.4}. For example, an analysis of the impacts of the shared socio-economic pathway (SSP) scenarios indicates that terrestrial biodiversity and regulating contributions will be more heavily impacted in Africa and South America than in other regions of the world, especially in a regional competition scenario and in an economic optimism scenario compared to a global sustainability scenario {4.2.1, 4.2.4.2}.

Irrespective of the underlying socio-economic assumptions, spatial telecoupling (socioeconomic and environmental interactions over distances) implies that increasing future demand for ecosystem services in certain regions will affect supply of services in others. Material contributions, especially food and energy production, play a dominant role in these telecouplings (*well established*) {4.2.4, 4.3.3, 4.5.2}. Material contributions tend to be traded between regions {4.1, 4.2.4.4., 4.2.4.5, 4.5.2, 4.6}, but locally declining biodiversity cannot be replaced by increased biodiversity in a different location {4.2.2-4.2.4}. If tele-couplings are not accounted for in future scenarios, unrealistically overoptimistic responses to a regional political intervention (e.g., land-based climate mitigation, negative emission policies, sustainable fisheries management for local resources and not for imported ones) are assumed, and measures to reduce detrimental side effects not taken (*established but incomplete*) {4.3.3}.

11 Limiting mean global warming to well below 2°C will have large co-benefits for nature and nature's contributions to people in marine, freshwater and terrestrial ecosystems. Land-based climate change mitigation efforts offer opportunities for co-benefits, but if large land areas are required, trade-offs with biodiversity conservation and food and water security goals will need to be addressed in terrestrial and freshwater ecosystems (*well established*). Climate warming and ocean acidification associated with increasing atmospheric CO_2 are already causing damage to marine, freshwater and terrestrial biodiversity (*well established*) {4.2.2, 4.2.3, 4.2.4} which confirms the urgency of meeting the goals of the Paris Climate Agreement. The degree to which marine and land ecosystems will continue to remove CO_2 from the atmosphere, which at present amounts to nearly 50% of anthropogenic CO_2 emissions, is highly uncertain {4.2.2.1, 4.2.4.1}. On land, reduction of deforestation combined with management practices in cropland, pastures and forests can contribute notably to greenhouse gas emissions reductions (*well established*). Recent cost-effective estimates are between ca. 1.5 and 11 Gt CO_2eq a^{-1} over the coming few decades, the undetermined range depending, amongst others, on which types of measures are included {4.5.3}. Along coastlines, a combination of reduced nutrient discharge (mitigating pollution) and space to allow inland wetland migration (adapting to sea level rise), is essential to preserve the capacity of coastal wetlands to sequester carbon (*established but incomplete*) {4.2.2.2.2, 4.2.2.5}.

Regionally, land conversion pressure is large both in scenarios of high population growth and lack of sustainability considerations, and in scenarios requiring land for bioenergy or afforestation and reforestation to mitigate climate change (*established but incomplete*) {4.1, 4.2.4.3}. Recent projections of an annual carbon uptake in 2050 projected for bioenergy pathways (with carbon capture and storage about 0.9-2.2 GtC a^{-1}) and afforestation/reforestation (0.1-1 GtC a^{-1}) are equivalent to an additional one third to three quarters of today's land carbon sink {4.2.4.3}. It remains uncertain whether the required land area would be available for large bioenergy plantations or afforestation/reforestation efforts, where these areas would be located and whether such net carbon uptake rates can be achieved and maintained {4.2.4.3, 4.5.2}. Likewise, detrimental environmental and societal side effects have been projected to arise from strong mitigation scenarios that rely on large area expansion of managed crop and forested land associated with intensification of production (*established but incomplete*) {4.2.4.3, 4.3.2.1, 4.5.2}.

12 Scenarios repeatedly show that changing food consumption patterns and reducing waste and losses in the food system can contribute significantly to mitigating loss of biodiversity and ecosystem services. Human population growth over the coming decades is projected to increase to nearly 9.8 billion (± 0.4 billion) by 2050 and to 11.4 billion (± 1.8 billion) by 2100. As a consequence of the projected population growth, continued urbanisation, and changes in many countries' diets towards increasing per capita animal protein share and processed food, most scenarios foresee increasing crop area, and in some cases pasture area as well. These projected changes in agricultural land area are combined with intensification of land management and continued increases in crop yields, that are projected to have detrimental environmental and biodiversity side effects associated with agricultural intensification (*well established*) {4.2.2.4.2, 4.3.2.1, 4.3.2.2, 4.5.2}. An increasing number of scenarios emphasizes the potential role of consumption as part of the solutions to overcome these challenges, such as shifting diets towards a globally equitable supply of nutritious calories or reducing wastes and losses along the entire chain from crop production to consumers (*well established*) {4.5.4}. Enhancing efficiencies in the food system has large potential to free up land for other uses such as for biodiversity conservation. Studies that explore dietary scenarios of reduced consumption of animal protein estimate that between ca. 10% and 30% of today's area under agriculture may be freed for other purposes, with possible co-benefits in the form of a globally more equitable distribution of animal protein intake by humans and improved health. Reduced greenhouse gas emissions from the land sector, and reduced irrigation water needs are an additional benefit, which will also release pressure on freshwater pollution and biodiversity (*established but incomplete*). Nearly one-quarter of total freshwater used today in food crop production are estimated to be spared if wastes and losses in the food system were minimized (*inconclusive*) {4.3.1, 4.3.2, 4.5.2, 4.5.3}.

13 Societies and individuals within societies value differently the regulating, material, and non-material contributions from nature that underpin their quality of life (*well established*). In future scenarios governed by market forces, multiple dimensions of good quality of life are expected to decline. The decline is particularly pronounced for indicators related to livelihood and income security (*established but incomplete*) {4.4.1, 4.4.2}. Market-based and regionally-fragmented scenarios, associated with growth in population and consumption, indicate continuous deterioration of nature to support economic growth, with some regions affected more than others. Without decoupling economic growth from unsustainable extraction and uses, scenarios show continuous decline in nature's contributions to people. Scenarios exploring sustainability or reformed financial market pathways are projected to result in improved good quality of life (*established but incomplete*) {4.4.1, 4.4.2}. In general, the lack of explicit consideration in global scenarios of good quality of life explicitly, and its regionally and socially differentiated nature, impedes robust projections into the future, in particular for non-material aspects. Interactions of future changes in nature, its contributions to people and good quality of life can be better understood and, therefore, potentially better anticipated and managed, when they are evaluated at regional scales as well as the global scale.

Small-scale farming, fishing and other communities, and Indigenous Peoples around the world that depend directly on local environments for food production, especially in low-income countries, are particularly vulnerable to climate-related food insecurity, which raises important equity and fairness issues. Similarly, in coastal regions, decreases in precipitation and fresh water supplies, along with projected increases in sea level, sea surface temperatures and air temperatures, and ocean acidification are projected to have major negative effects on water security for societies. Nature-based livelihoods may become precarious with intensifying future trends in environmental change (*established but incomplete*) {4.4.1, 4.4.2}. Future threats to biodiversity and ecosystem services also constitute imminent challenges to the cultural identity of communities, particularly when faced with environmental degradation (*unresolved*) {4.4.2}.

14 The role of people's knowledge, values and traditions, and their potential future changes have been barely explored in global scenarios of future socio-economic and environmental change. A challenge to the assessment of nature's contribution to people and good quality of life under different future scenarios is their socially differentiated nature. People's values and traditions are crucial in shaping the future, yet they are rarely central to scenario exercises (*established but incomplete*) {4.4.1}. Novel methods are beginning to be developed to fully integrate people's worldviews into scenario planning, however transcendental values held by the social groups have so far not been well incorporated. The process of elaborating scenarios with participatory approaches is increasingly taking into account value negotiations around the meaning of good quality of life (*established but incomplete*) {4.4.2}. Consequently, ethical questions emerge regarding how to build scenarios so that local knowledge, particularly that of Indigenous Peoples and Local Communities (IPLCs), are not coopted in ways that may exacerbate processes of their social marginalization.

15 Different social groups experience change in ecosystem function and services differently so that a given change scenario usually implies winners and losers in terms of the projected impacts on good quality of life (*established but incomplete*) {4.4.1, 4.4.2, 4.4.3}. People vary in their access to ecosystem services, exposure to disservices, dependence on ecosystems, needs and aspirations. These are further mediated by societal structures and norms as individual characteristics and power relations {4.4.2, 4.4.3}. Many IPLCs are found in protected areas, where dimensions of good quality of life such as food and energy security may trade off with other dimensions of ecosystem functioning. Indirect drivers of change such as climate mitigation policy (e.g., REDD+) may disproportionately impact the possible trajectories towards achieving good quality of life by IPLCs (*unresolved*) {4.4.1}.

Thus, decision-making about environmental management with implications for different bundles of ecosystem services is an intently political process, with often divergent stakeholder interests and power dynamics. Evaluating the implications for the good quality of life of IPLCs under different scenarios of change can benefit from deliberative and participatory approaches that consider a wide range of stakeholder views, and disciplinary perspectives. Such a diversity of perspectives needs to draw on indigenous and local knowledge, to take account of the multiple interacting factors and socially differentiated experiences, vulnerabilities and preferences (*established but incomplete*) {4.4.2, 4.4.3}. A limitation with participatory approaches is the difficulty of imagining future scenarios of changes in the 'demand side' of nature's contributions. So, a group may discuss how changes in a resource might be affected by climate change, but it is often framed in terms of current social conditions. Likewise, participatory approaches are likely to be more successful if the scale of scenarios (e.g., local, regional, global) and stakeholder group perspective can be matched.

16 Most internationally agreed policy goals and targets for biodiversity are missed by most countries under business-as-usual scenarios because the current patterns and future trends of production and consumption are not environmentally sustainable. Indeed, trajectories of most biodiversity indicators under business-as-usual increasingly deviate from targets over time (*well established*) {sections 2 and 6}. The achievement of most biodiversity targets therefore requires a steer away from the current socio-economic trajectory and the worldviews and values that underpin it (*well established*). Scenarios that assume increased sustainability show that achieving most SDGs is possible at some point in the future, but this requires substantive and immediate action (*established but incomplete*) {4.6.1}, and the time horizon of the possible achievement of the SDGs is undetermined.

Scenarios and models can support the formulation of future biodiversity targets in terms of concept, phrasing, quantitative elements, and selection of indicators to monitor progress (*established but incomplete*). Scenario and models are also amenable to exploring interactions among targets (*well established*). For example, scenarios have shown that ambitious protected area expansion plans would conflict with agricultural production under business-as-usual assumptions, and that achieving SDGs for both biodiversity and hunger would require a 50-70% increase in land productivity (*inconclusive*) {4.6.1}.

Focusing future quantitative targets for biodiversity on management outcome rather than effort may improve policy implementation and related management decisions. For example, the numeric component of Aichi BiodiversityTarget 11 relates to the global proportion of protected areas. But the aim of protected areas is to achieve the long-term conservation of nature, which suggests to move the focus to the amount of nature that is protected and the effectiveness of protection rather than proportion of area under protection. Scenarios and models have shown that the outcome of a protected area network is determined by its location, connectivity and management, other than its size.

17 There is a lack of global-scale impact analyses that integrate across natures, nature's contributions to people and good quality of life. Most scenarios developed for global environmental assessments have explored impacts of humans on ecosystems, such as biodiversity or productivity loss {4.1, 4.2}. The effects of alternative trajectories of socioeconomic development on ecosystems and ecosystem services have been assessed as one-way outcomes, ignoring the possible interactions between natural and socioeconomic systems. A better understanding of feedback mechanisms is needed on many fronts, for instance: in what ways pollution arising from agricultural intensification does impact pollinators and/or water quality, which in turn impact land use and intensification? How do changes in food prices arising from different land uses feed back to land-use decision-making? How is overfishing leading to the depletion of large predatoryfish and development of global markets for alternative species, often their own prey, leading to further collapse of marine resources? To what extent climate change induced sea level rise is decreasing wetland area and is affecting carbon sequestration? (*established but incomplete*) {4.1, 4.3.2.1, 4.5.1-4.5.3, 4.6.1, 4.7.3}. In addition, storylines of socio-economic development that underlie global scenarios consider mostly material aspects of GQL and do not consider other indicators of GQL {4.4.1-4.4.3}. There is a knowledge gap in scenario studies about non-material contributions to people compared to material contributions and regulating contributions, which limits our capacity to understand quantitatively how nature, its contributions to people and good quality of life interact and change in time.

In particular, human decision-making at multiple levels is not well integrated in global scenario modelling tools such as Integrated Assessment Models that focus on economic objectives (*well established*) {4.1, 4.2, 4.5.1, 4.5.2, 4.4.1-4.4.3}. A paradigm shift in scenario design could be achieved by considering, alongside of economic principles, provisioning of multiple ecosystem services and GQL as part of the storyline and human decisions (and subsequent scenario realisation), rather than as an outcome of socio-economic drivers {4.6.1}. For a more robust scientific underpinning of biodiversity and multiple sustainability targets, these non-material aspects need to be explicitly addressed in the scenarios (*unresolved*) {4.6.1}. Such scenarios would facilitate policy-relevant scientific evidence through exploration of trade-offs and co-benefits between targets related to biodiversity and ecosystem services, including the interconnected nature of drivers across regions {4.3.4, 4.5.1}. Participatory Scenario Planning, with stakeholders aligned to the scale of the scenario (e.g., the CBD for global scenarios) would allow for a differentiated assessment of good quality of life across stakeholder groups and highlighting winners and losers across environmental or policy scenarios (*established but incomplete*) {4.4.2}.

18 **Large uncertainties remain in future scenarios and related impact studies at the global scale.** Careful analysis and communication of sources of uncertainty in scenarios and models are vital when using them in support of decision-making (*well established*). Global modelling tools to explore futures of biodiversity and futures of ecosystem state and function are still mostly disconnected and do not consider diversity-function links {4.2, 4.7}. Projected future changes in species ranges, community diversity or ecosystems may be under- or overestimated by most studies because they do not explicitly account for impacts of multiple drivers, adaptive capacity of species and for feedbacks arising from species interactions {*established but incomplete*) {4.2.5, 4.5}. Effectively linking scenarios and models across spatial and temporal scales is methodologically difficult and in early stages of development and use but can make important contributions to decision-making when achieved (*established but incomplete*). However, linking must be done with considerable caution because it creates additional complexity that can make the behaviour of scenarios and models difficult to understand and may introduce important sources of uncertainty {4.5, 4.7}. Substantial efforts are needed to identify uncertainty related to models and scenarios and improve the treatment of uncertainty between and within models {4.2, 4.6, 4.7}. Strong, sustained dialogue between modellers, stakeholders and policymakers are one of the most important keys to overcoming many of the significant challenges to dealing with uncertainty and scales issues when mobilizing scenarios and models for decision-making.

4.1 INTRODUCTION

4.1.1 Context and objectives of the chapter

Rapid biodiversity loss and its adverse consequences for nature, nature's contributions to people and Good quality of life clearly remain as key challenges for the coming decades. Economic inequality, societal polarization and intensifying environmental threats have been identified by the World Economic Forum's *Global Risks Report (GRR) 2017* (WEF, 2017) as the top three challenges for global developments over the next decade or more. For the first time, all five environmental risks in the report (extreme weather; failure of climate change mitigation and adaptation; major biodiversity loss; natural disasters; human-made environmental disasters) were ranked both high-risk and high-likelihood (WEF, 2017). These challenges emphasize the importance of the UN 2030 Agenda and the Sustainable Development Goals (SDGs) and the 2050 Global Vision for Biodiversity to facilitate a sustainable future state for the planet, with a recognition of the connections between humans and ecosystem well-being at their core (Costanza *et al.*, 2016).

This chapter focuses on the assessment of scenarios and models that have been used to explore a wide range of plausible futures of nature, nature's contributions to people (NCP) and good quality of life (GQL), focusing on the current-to-2050 time frame and on continental to global spatial scales. One objective is to alert decision makers to potential undesirable impacts of a broad range of plausible

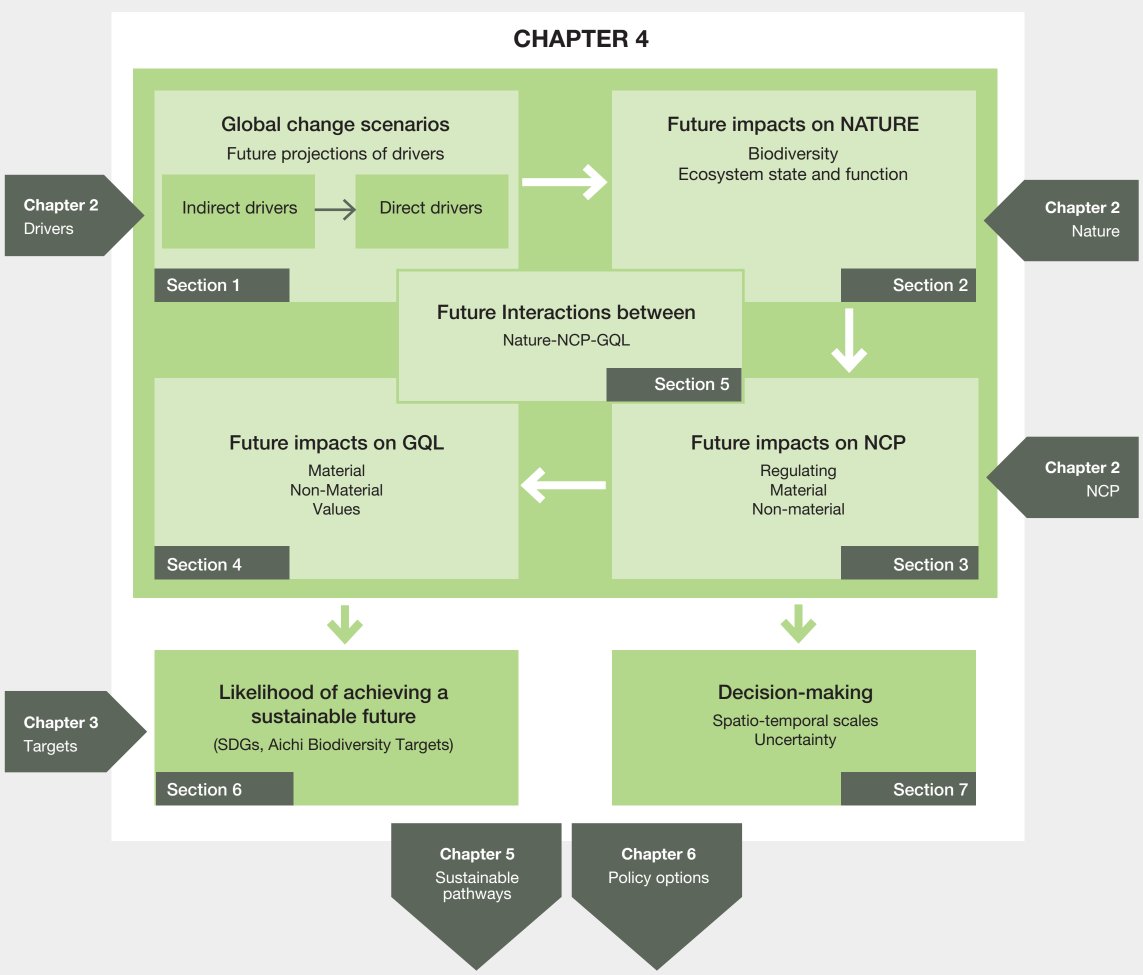


Figure 4 1 1 **Scope of Chapter 4 "Plausible futures of nature, its contributions to people and their good quality of life" of the IPBES Global Assessment, content of sections and their relationships, and linkages with the other chapters of the Global Assessment. NCP: nature's contributions to people; GQL: good quality of life.**

socio-economic development pathways. A second objective is to highlight development pathways and actions that can be taken to minimize impacts, as well as restore nature and enhance its contributions to people. As is clearly highlighted in Chapters 2 and 3 of this assessment, the context is that pressures, such as resource exploitation and climate change, continue to increase, and most measures of the state of nature and nature's contributions to people continue to decline. This chapter is designed to help understand the conditions under which these trends might accelerate vs. stabilize or even improve over the coming decades.

Scenarios are a means of exploring plausible future trajectories of direct and indirect drivers of environmental change (IPBES, 2016b). Models provide a means to estimate qualitatively or quantitatively the impacts of indirect and direct drivers on nature and nature's contributions to people (IPBES, 2016b). Building upon an analysis of drivers of change presented in chapter 2.1, this chapter starts with an assessment of the key underlying assumptions about drivers in scenarios and a synthesis of the projected trajectories of key direct drivers, such as climate change and land-use change, and indirect drivers, such as human population and economic growth, over the next several decades and places these in the context of current trends (section 4.1; **Figure 4.1.1**, see Chapter 2.1).

Sections 4.2 and 4.3 of this chapter focus on the assessment of a wide range of quantitative models that have been used to project future dynamics of nature and its contributions, and these sections also place these projections in the context of observed trends as well as the current understanding of the mechanisms underlying these trends (see Chapter 2). Models can also be used to evaluate the impacts of changes in nature and its contributions on quality of life, but this has rarely been done (IPBES, 2016b). As such, section 4.4 focuses on the underlying assumptions about quality of life embedded explicitly or implicitly in models and scenarios, as well as making qualitative connections with modeled impacts on nature and its contributions. Projected synergies and trade-offs between nature, NCP and GQL are explored in section 4.5.

Finally, comparisons of scenarios and model outcomes are then made with internationally agreed objectives, such as the Sustainable Development Goals for 2030 and the Convention on Biological Diversity's 2050 Vision, in order to better understand the types of socio-economic development pathways that lead to outcomes that are closest to or furthest from these objectives (section 4.6). This is then put in the broader context of the use of scenarios and models in decision-making (section 4.7), with a focus on the importance of scales and uncertainty in the use of models and scenarios to inform decisions.

Chapter 5 follows by providing a more in-depth analysis of "target-seeking" scenarios designed to evaluate sustainable futures, including evidence regarding sustainable transition pathways, for which specific policy options are discussed in Chapter 6.

4.1.2 Exploratory scenarios

Scenarios can be defined as plausible representations of possible futures for one or more components of a system, or as alternative policy or management options intended to alter the future state of these components (IPBES, 2016b). They provide a useful means of dealing with many distinct possible futures (Cook *et al.,* 2014; Pereira *et al.*, 2010). Policy and decision-making processes rely on estimates of anticipated future socio-economic pathways, and knowledge of the potential outcomes of actions across distinct geographic regions, sectors and social groups. The process of scenario development itself can help to build consensus by integrating the objectives of different stakeholder groups (Priess & Hauck, 2014). This is particularly germane in efforts that seek to integrate the knowledge, perspectives and goals of local stakeholders, particularly Indigenous Peoples and Local Communities (IPLCs), who are frequently marginalized from policy and decision-making processes (IPBES, 2016b; Petheram *et al.*, 2013).

When assessing future impacts on nature, its contribution to people and related good quality of life, there is a need to link the trajectory of direct and indirect drivers to different future scenarios. Exploratory scenarios can be either qualitative, in the form of storylines, or quantitative, in the form of model outputs (van Vliet & Kok, 2015). The main objective of exploratory scenarios is informing stakeholders of the potential impacts of different driver combinations, e.g., a proactive set of actions that may increase the likelihood of social, economic or political targets versus a "business-as usual" scenario that involves no major interventions or paradigm shifts in the organization of functioning of a system. Exploratory scenarios may provide a plurality of plausible alternative and contrasting futures.

Exploratory scenarios for global scale environmental studies and assessments have been developed for a range of UN related assessments, including scenarios developed under the IPCC process, such as the so-called SRES scenarios (Nakicenovic *et al.*, 2000) in the late 1990s, the Representative Concentration Pathways (RCPs) and the recent Shared Socio-economic Pathways (SSPs), as well as scenarios considered for the UNEP Global Environmental Outlook (GEO) (UNEP, 2012) process, Global Biodiversity Outlook (GBO) and the Millennium Ecosystem Assessment (MA, 2005). The Global Scenario Group has also developed a range of contrasting global scenarios (Raskin *et al.*, 2002).

In addition, organizations such as FAO, OECD, IEA and UNESCO have developed several scenarios for specific purposes, such as the OECD Environmental Outlook to 2050 where a trend-based scenario was developed and a large number of policy alternatives were evaluated (OECD, 2012). Several of these scenarios have been evaluated by Integrated Assessment Models (IAMs) to specify and quantify ecological and environmental changes, including climate change, land-use change, vegetation dynamics and water (Kok *et al.*, 2018).

An important advance in the last few years has been to link representative concentration pathways (RCPs) with shared socio-economic pathways (SSPs) (O'Neill *et al.*, 2014) in support of the IPCC process, to inform deliberations under the UN Framework Convention on Climate Change (UNFCCC). Some of these scenarios imply significant mitigation efforts in the land-use sector, including large-scale reforestation and afforestation, or bioenergy crops with implications for both biodiversity and ecosystem services (Riahi *et al.*, 2017).

Existing environmentally relevant scenarios include scenarios that are most often either exploratory (this chapter focus) or target-seeking (Chapter 5) (IPBES, 2016b). In many cases, these scenarios may be appropriate for specific temporal or spatial scales or limited in scope (e.g. relevant to one or a few sectors). They can also be incomplete with regard to quantitative information about nature, NCP and GQL, and thus less useful for the purposes of this IPBES assessment. This is because integrated assessment models that often underpin scenarios of future greenhouse gas emissions, land-use change, or demand for food have a strong economic perspective and do not consider e.g., monetary or non-monetary values of ecosystem services. Issues related to conservation or biodiversity, or feedbacks from changes in ecosystem services to socio-economic decision-making, have typically not been well considered in the wide range of global scenarios that are well established in the climate change scientific communities. Likewise, scenarios of the future of biodiversity typically do not seek to quantify the possible co-benefits related to ecosystem services (Kok *et al.*, 2017; Pereira *et al.*, 2010; Powell & Lenton, 2013). Important gaps remain in scenario development, such as the development of integrated scenarios for areas projected to experience significant impacts and possible regime shifts (e.g. Arctic, semi-arid regions and small islands), and socioeconomic scenarios developed for and in collaboration with Indigenous Peoples and Local Communities (IPLCs) and their associated institutions, values and worldviews (Furgal & Seguin, 2006).

4.1.3 Archetype scenarios

From the many scenarios developed in the last few decades, it is apparent that groups of scenarios have many aspects of their underlying storylines in common and may be considered as "archetype scenarios". Archetypes represent synthetic overviews of a set of assumptions about the configuration and influence of direct and indirect drivers used in scenarios. They vary mainly in the degree of dominance of markets, dominance of globalization, and dominance of policies toward sustainability. Hunt *et al.* (2012) and van Vuuren *et al.* (2012) analysed a large number of local and global scenarios and came to the similar

Box 4 1 1 Scenario archetypes.

(from Hunt *et al.,* 2012; IPBES, 2016b; van Vuuren *et al.*, 2012; see also section 5.2.2 in IPBES, 2018i): description of underlying storylines, and links with indirect and direct drivers.

Economic Optimism. Global developments steered by economic growth result in a strong dominance of international markets with a low degree of regulation. Economic growth is assumed to coincide with low population growth due to a strong drop in fertility levels. Technology development is rapid and there is a partial convergence of income levels across the world. Environmental problems are only dealt with when solutions are of economic interest. The combination of a high economic growth with low population growth leads to high demands of commodities and luxury goods. These demands will however be unequally distributed among regions and within regions. Consequently, energy use and consumption are high. In addition, high technological development in combination with increased global market leads to high yields in agricultural and wood production on the most productive lands. Therefore, pollution and climate change will be relatively high, but land use relatively low. Direct exploitation will continue but also replaced by cultivation of for example fish and livestock. Global trade will increase the risks of invasive species.

Reformed Markets. Similar to the economic optimism scenario family but includes regulation and other policy assumptions to correct market failures with respect to social development, poverty alleviation or the environment. Thereby, relative to the economic optimism archetype, high demands for goods are expected to be more equally distributed and pollution will be lower.

Global Sustainable Development. A globalized world with an increasingly proactive attitude of policymakers and the public at large towards environmental issues and a high level of regulation. Important aspects on the road to sustainability are technological change, strong multi-level governance, behavioural change through education, and a relatively healthy economy. All variations of this archetype are beneficial for biodiversity. This scenario combines a low population growth with moderate economic development, and sustainable production and consumption. Low demands of especially luxury goods are expected, and a shift in diet towards less meat can be expected. Energy use will be low to moderate and fossil fuel use will be reduced, leading to low climate change and low land-use change. Due to environmental policies and sustainable production, pollution will be lower and direct harvesting will partly be replaced by cultivation. The global focus will increase the risk of invasive species

Regional Sustainability. A regionalized world based on an increased concern for environmental and social sustainability. International institutions decline in importance, with a shift toward local and regional decision-making, increasingly influenced by environmentally aware citizens, with a trend toward local self-reliance and stronger communities that focus on welfare, equality, and environmental protection through local solutions. The scenario combines a low economic growth with moderate population growth rates. The demands for goods are low and production focusses on sustainability with low levels of energy use or environmental degradation associated with higher importance for intrinsic and relational values of nature. Low rates of climate change are expected. Supply of agricultural products will be organised with regions with low levels of global trade. A slow technological development and a sub-optimal land use lead to relatively high rates of land-use change. Direct exploitation of natural systems will be within the carrying capacity of natural systems, and risks for invasive species will be relatively low.

Regional Competition. A regionalized world based on economic developments. The market mechanism fails, leading to a growing gap between rich and poor. In turn, this results in increasing problems with crime, violence and terrorism, which eventuates in strong trade and other barriers. The effects on the environment and biodiversity are mixed. Overall, there is a tendency towards increased security, which can either be positive (protect biodiversity) or negative (intensify agricultural production). Particularly in low-income countries, deforestation and loss of natural areas are a risk. In this scenario, due to a lack of global co-operation and trade, a high population growth is expected combined with low economic growth. Thereby, the demand for goods including agricultural products increases, but the demand for luxury, energy intensive goods is relatively low, and thus relatively low climate change is expected. Agricultural supply will be mainly within regions, which, combined with slow technological development, will result in lower productivity and high rate of land-use change. Direct exploitation will continue, low rates of replacement by cultivation are expected. The risk of invasive species will be lower than in the archetypes that focus on globalization.

Business-As-Usual. Assumes that the future can be characterised by a continuation of historical trends, including the implementation of international agreements. Sometimes referred to as a reference scenario, or as a middle-of-the-road scenario. It can also be considered as a less extreme variant of the economic optimism archetype. Business-as-usual is characterized by moderate economic growth, moderate population growth and moderate globalization. Demands are not high nor low, and in combination with moderate technological development, environmental changes will also be moderate.

conclusion that four to six scenario archetypes cover the large range of possible futures **(Box 4.1.1)**.

This chapter makes frequent reference to archetype scenarios because the use of scenario archetypes was also adopted in the IPBES regional assessments. This approach helped to synthesize results across a very broad range of scenario types. Synthesis across regional assessments is hampered by the use of different archetype classifications for each of the regions, which was done in order to match archetypes to regional contexts.

The IPBES methodological assessment on scenarios and models (IPBES, 2016b) adopted the “scenario families”, as described in van Vuuren *et al.* (2012), which include the scenario archetypes **(Box 4.1.1)** distinguished by Hunt *et al.* (2012).

The different scenario archetypes describe different visions of the future (de Vries & Petersen, 2009), reflecting different values, guiding principles of society, understanding of good quality of life, approaches to decision-making and distribution of power (among other aspects). These aspects are often included in scenarios as implicit assumptions and have a large impact on the outcomes of the scenarios. For example, some scenario archetypes may prioritize intrinsic values of nature, while others may emphasize instrumental or relational values (Pascual *et al.*, 2017). These differences ultimately affect the different archetypes in various ways. **Table 4.1.1**. shows all these aspects synthesized across the six scenario archetypes. The most common global scale scenarios encountered in the literature can be assigned to these archetypes **(Table 4.1.2)**, with the caveat that individual scenarios do not match all of the characteristics of the archetype defined in **Table 4.1.1** and **Box 4.1.1**.

Analysis of the data sourced from the systematic literature review (Appendix A4.1.1) carried out as part of the background work for this chapter indicates a skewed representation of scenarios between and across the three components nature, NCP and GQL **(Table 4.1.3)**. This skew reflects to some extent the length of time scenarios have been available, but also reflects a bias towards climate change related scenarios. The analysis shows

Table 4 1 1 **Different guiding principles, values, approaches to good quality of life (GQL), distribution of power and decision-making approach across scenario archetypes.**

	Economic optimism	Reformed Markets	Global Sustainable Development	Regional Sustainability	Regional Competition	Business-As-Usual
Guiding Principles	Prosperity based on economic growth	Economic efficiency & sustainability	Global Sustainability	Equity & local sustainability	Individualism and safety concerns	No change
Main value in human-nature relationships	Instrumental / Utility value	Instrumental / Utility value	Intrinsic / Relational	Relational	Instrumental / Utility value	Instrumental / Utility value
Environmental principles	More "efficient" use of nature with new technologies, but protection is not prioritised	Use of nature is regulated with reformed polices	Protecting nature and environmental sustainability	Local sustainable use of nature	Lack of concern/ low priority for nature	Overexploitation of nature with elements of regulation and protection
Social principles	Individualism	Individualism with elements of cooperation	Global cooperation	Cooperation within the community	Individualism in a fragmented world	Individualism with elements of cooperation
Economic principles	Market oriented based on profit maximization	Market regulation based on efficiency & sustainability targets	Market regulation and non-market mechanisms based on global environmental sustainability and equity	Markets oriented to local environmental and quality of life priorities.	Market oriented with trade barriers and growing economic asymmetries / polarisation.	Market oriented with some barriers and some regulation
Approach to good quality of life	Material aspects	Material aspects, health and other GQL components included in international goals (e.g. SDG)	Respect for nature at the global scale is important for GQL	Livelihoods, Social relationships and health	Public security	Material aspects, and other components such as health, public security
Power relations among countries	Large countries powerful	Power imbalance moderated by negotiation	Power balanced by global institutions and collaboration	Decentralized among and within countries	High differences in power among regions	Large countries are powerful, power partially balanced by negotiation, high differences in power among regions
Decision-making processes	Top-down	Top-down	Horizontal / Participatory	Bottom-up / Participatory	Top-down with growing exclusion (marginalisation) of the poorest (most vulnerable) regions & social groups	Top-down
Powerful stakeholders	Private sector	Alliance of governments and private sector	Balance of power among the various stakeholders, global institutions	Communities	National Governments and private sector	Private sector & governments, with participation of NGOs

the available literature is strongly dominated by studies of future trajectories of nature, with considerably fewer studies on NCP and very few studies providing information on GQL. This may reflect the lack of integrated assessment tools available to conduct this type of work quantitatively. This inconsistency of coverage constrained the work in this chapter, and explains the emphasis put on nature (section 4.2).

Table 4 1 2 **Scenarios from earlier global assessments attributed to archetypes or families.**

Source: IPBES, 2016b; van Vuuren *et al.*, 2012.

Source	Economic Optimism	Reformed Markets	Global sustainable development	Regional Sustainability	Regional Competition	Business-As-Usual
SRES	A1F1		B1 (A1T)	B2	A2	B2
GEO3/GEO4	Market first	Policy first	Sustainability first		Security first	
Global scenario group	Conventional world	Policy reform	New sustainability paradigm	Eco-communalism	barbarization	
Millennium Ecosystem Assessment		Global Orchestration	Technogarden	Adapting mosaic	Order from strength	
OECD Environmental Outlook						Trend
Shared Socio-economic Pathways	SSP5		SSP1		SSP3/SSP4	SSP2
Representative Concentration Pathways (RCP)	RCP8.5		RCP 2.6		RCP 6.0	RCP 4.5
Roads from Rio/ fourth Global Biodiversity Outlook		Consumption Change	Global technology	Decentralized Solutions		Trend

Table 4 1 3 **Classification of studies according to scenario represented along a continuum from nature via NCP (nature's contributions to people) to GQL (good quality of life) focused studies.**

The number of papers reported comes from the systematic literature review conducted for this chapter (Appendix A4.1.1).

Scenario	All	Nature	NCP	GQL
RCP8.5	237	198	39	0
RCP6.0	9	9	0	0
RCP4.5	50	41	9	0
RCP2.6	150	144	6	0
A1	6	4	1	1
A1b	119	108	8	3
A1B	4	0	4	0
A1F1	76	76	0	0
A1T	1	0	1	0
A2	200	191	7	2
B1	113	106	6	1
B2	123	117	5	1
SSP1	1	0	1	0
SSP2	13	1	12	0
SSP3	2	1	1	0

Scenario	All	Nature	NCP	GQL
SSP5	1	1	0	0
BAU	23	20	3	0
Global orchestration	13	11	2	0
Order from strength	12	9	3	0
Technogarden	11	10	1	0
Adapting mosaic	8	7	1	0
Consumption change	6	6	0	0
Global Technology	3	0	3	0
Decentralized solutions	1	1	0	0

4.1.4 Projected indirect and direct drivers of change in scenarios

The main indirect drivers of change of nature and its contributions to people, and consequently the quality of life include economic development, demographic trends and factors, technological development, governance and institutions, and various socio-cultural aspects such as worldviews and values. These indirect drivers have multiple impacts on direct drivers of change, which include climate change, land-use change, pollution, direct harvesting, invasive species and disturbance. In each scenario archetype, assumptions on the indirect drivers lead to different combinations of direct drivers **(Box 4.1.1)**.

Drivers are always multiple and interactive, so that one-to-one linkage between particular drivers and specific changes in ecosystems rarely exists. The causal linkage between drivers is often mediated by other factors or a complex combination of multiple factors, thereby complicating the understanding of causality or attempts to establish the contributions by the various drivers to changes in nature, NCP and GQL (see also Bustamante *et al.*, 2018; Elbakidze *et al.*, 2018; Nyingi *et al.*, 2018; Wu *et al.*, 2018). The cumulative effects of multiple stressors may not be additive but may be magnified by their interactions (synergies) and can lead to critical thresholds and transitions of ecological systems (Côté *et al.*, 2016). Cascading impacts of co-occurring stressors are expected to degrade ecosystems faster and more severely (section 4.7 in Bustamante *et al.*, 2018).

4.1.4.1 Indirect Drivers (including consideration of diverse values) in scenarios

Indirect drivers (also referred to as 'underlying causes') operate diffusely by altering and influencing direct drivers as well as other indirect drivers (also see chapter 1 in this report and IPBES, 2016b). They influence human production and consumption patterns with subsequent environmental implications. Economic drivers, including trade and finances, and demographic drivers interact with other indirect drivers such as technology, governance/institutions and social development including equity. Archetype environmental scenarios for this century consider explicit reference to relevant indirect anthropogenic drivers in different combinations, as indicated in **Table 4.1.4**.

Economic development has historically been the key indirect anthropogenic driver of changes in nature, NCP and GQL, across all scales (global, regional, national and local). World GDP (at constant 2010 USD) increased by 6.9 times between 1960 to 2016 (based on Worldbank, 2017). Taking a historical perspective, past and prevailing patterns of production and consumption embodied in global economic trends have generated growing pressures on natural resources, the environment, and ecosystem functions. In all scenarios, world GDP will continue to grow **(Table 4.1.5)**. However, some studies also refer to the plausibility of sustainable de-growth, as a transformative pathway leading to a steady-state at a reduced level of economic output (Schneider *et al.*, 2011).

Economic activities, international trade and financial flows are closely related, particularly in recent decades due to increasing economic globalization. These considerably influence changes in nature, NCP and GQL through various direct and indirect pathways. In turn, these pathways are influenced by a number of policy channels and mechanisms, like trade policies, including incentives (tax exemptions, subsidies) and trade barriers, the dynamics of foreign debt and foreign debt service, flows of foreign direct investments, and monetary policies (dynamic of exchange rates, interest rates).

Demographic trends are a major indirect anthropogenic driver of changes in nature, NCP and GQL, across

Table 4 1 4 **Selected indirect drivers in archetype scenarios.**

Source: Based on Cheung *et al.* (2016: table 6.3); van Vuuren *et al.* (2012).

Selected indirect drivers	Archetype / scenario family					
	Economic Optimism	Reformed Markets	Global sustainable development	Regional Sustainability	Regional Competition	Business-As-Usual
Economic development	Very rapid	Rapid	Ranging from slow to rapid	Medium	Slow	Medium
Trade	Globalisation	Globalisation	Globalisation	Trade barriers	Trade barriers	Weak globalisation
Technological development	Rapid	Rapid	Ranging from medium to rapid	Ranging from slow to rapid	Slow	Medium
Population growth	Low	Low	Low	Medium	High	Medium
Policies & institutions (Governance)	Policies create open markets	Policies reduce market failures	Strong global governance	Local steering	Strong national governments	Mixed

Table 4 1 5 **Economic development (in GDP PPP) for the scenario archetypes.**

Source: MA, 2005; Nakicenovic *et al.*, 2000; OECD, 2012; Raskin *et al.*, 2002; Riahi *et al.*, 2017; UNEP, 2007). Global GDP was approximately 50 trillion $ at purchasing power parity in 2000. GDP PPP: Global Domestic Product based on purchasing power parity.

	GDP PPP in trillion 2000 US$					
	Economic Optimism	Reformed Markets	Global sustainable development	Regional Sustainability	Regional Competition	Business-As-Usual
2050	182-323	181-229	168-251	139-145	106-198	145-241
2100	458-895	427	213-498	310	177-321	310-473

all scales (global, regional, national and local). World population increased by 2.5 times, respectively between 1960 and 2016 (based on the World Bank Database, 2017). Population / demographic drivers consider changes in population size, migration flows, urbanization as well as demographic variables such as population distribution and age structure. Urbanisation driven by growing populations and internal migration acts as an indirect driver of land-use change through various ways, including through linear infrastructures such as transportation networks as well as synergies with other forms of infrastructure development (IPBES, 2016b). By 2050, all archetype scenarios project great increase in human population size, while towards the end of the century, downward trends are projected for the "economic optimism" (SSP5), "global sustainable development" (SSP1), "reformed markets" scenarios **(Table 4.1.2, Figure 4.1.2)**.

Per capita GDP trends combine the impacts of GDP and population growth on environment. Growing per capita GDP has historically implied increasing demand of key natural resources such as food, water and energy with adverse impacts on ecosystems and biodiversity, due to the persistence of unsustainable patterns of production and consumption. Humanity's demand has exceeded the planet's biocapacity for more than 40 years, and the Ecological Footprint shows that 1.6 Earths would be required to meet the demands humanity makes on nature each year, with consumption patterns in high-income countries resulting in disproportional demands on renewable resources, often at the expense of people and nature elsewhere in the world (WWF, 2016).

Technology development can significantly increase the availability of some ecosystem services, and improve the efficiency of provision, management, and allocation

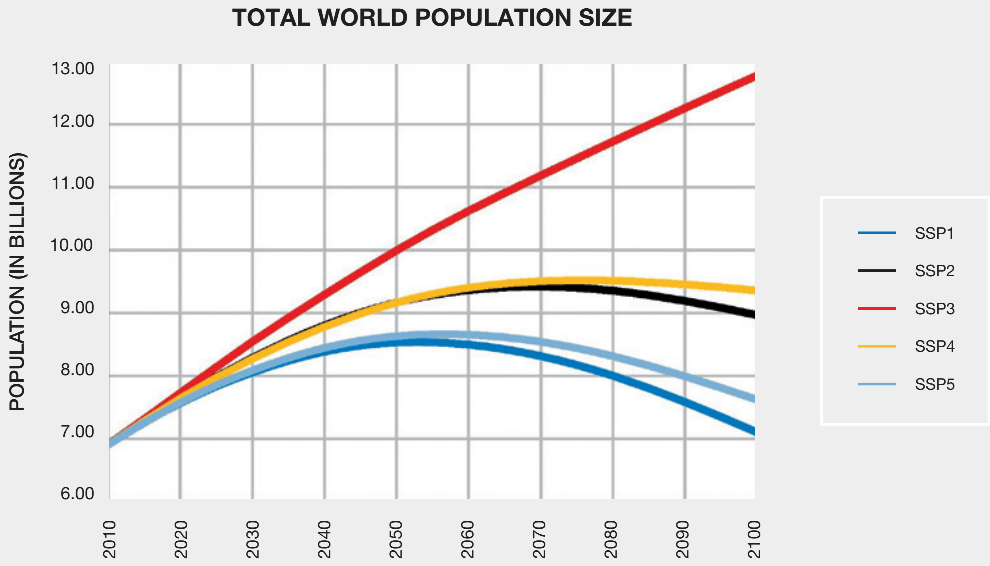


Figure 4 1 2 **Projected changes in world population according to the five Shared Socio-economic Pathways (KC & Lutz, 2017).**

Note: For the narratives of the SSPs, see O'Neill *et al.* (2017).

of different ecosystem services, but it cannot serve as a substitute for all ecosystem services. Technologies associated with agriculture and other land uses have a large impact as drivers of biodiversity and ecosystem change (IPBES, 2016a).

As part of the problem, some technologies can result in increased pressure on ecosystem services through increased natural resource demand as well as lead to unforeseen ecological risks, particularly natural resource intensive technologies, as those associated to agricultural land expansion (e.g., first generation of biofuels when produced unsustainably). In addition, climate change is directly related to the use of fossil-fuel-intensive technologies. As part of the solution, sustainability-oriented technological innovation may contribute to decouple economic growth and the consumption of natural resources through increasing efficiency, resilience and equity (e.g. agroecological food production systems) (IPBES, 2016a; Trace, 2016; Vos & Cruz, 2015).

Governance and institutions play an important role in the management of biodiversity, ecosystem services and ecosystem functions. Weak governance, including corruption, frequently leads to environmental mismanagement as well as the adoption of environmentally unsustainable policies, and growing conflicts (Pichs-Madruga *et al.*, 2016). The lack of recognition of indigenous and local knowledge (ILK) and institutions may also generate adverse consequences for nature, NCP and GQL as well as for Indigenous Peoples and Local Communities (IPLCs).

In addition to governments, new actors and coalitions (e.g. NGOs, researchers, indigenous groups) with different – and sometimes divergent and conflicting – perceptions and values are performing critical roles in environmental decision-making processes.

Social development and culture are critical ingredients of future scenarios on biodiversity, yet there is a lack of attention towards understanding how values, norms, and beliefs affect attitudes and behaviours towards the environment, and their roles in shaping the future and in driving transformation pathways. While there has been advances in methodologies supporting social-ecological analyses, emphasis has been on measurable indicators with less attention to the role of sociocultural values and practices in shaping other indirect drivers of change, and thus future pathways (Pichs-Madruga *et al.*, 2016).

Social inequity is a key concern in many regions, sub-regions, countries and territories. In many cases, poverty conditions correlate with increasing pressures on nature, but globally per capita consumption of natural resources is strongly correlated with affluence. World per capita private consumption, in dollars at constant 2010 prices, rose by 44.5% between 1990 and 2016 (Worldbank, 2017). The emergence of new waves of affluent consumers is projected to significantly increase the demand for already limited natural resources (Myers & Kent, 2003). For this reason, the impact of consumers' purchasing power on the demand of natural resources is receiving growing attention in scenarios. This discussion is very relevant in the context of the global debate on the Sustainable Development Goals (SDGs), multidimensional progress in human development (UNDP, 2016) and their interlinkages with nature and NCP.

4.1.4.2 Direct Drivers

Climate change

By the end of the 21st century, three of four explored Representative Concentration Pathways (RCP; van Vuuren *et al.*, 2011) result in an increase in global average surface temperatures above 1.5°C compared to the present-day reference period 1986-2005 (Stocker *et al.*, 2013). Averaged over years 2046-2065, temperature increases range from (model median) 1.4°C (RCP4.5) to 2.0°C (RCP8.5) above the reference period (1986-2005). Only the RCP2.6 scenario could possibly lead to a below 2°C world, with projected warming above the reference period from 0.3 to 1.7°C averaged over the last two decades of the 21st century, and from 0.4-1.6°C for years 2046-2065. Warming will be larger over land and by far highest in the Arctic. The frequency of extreme hot weather events will increase (Stocker *et al.*, 2013). Precipitation patterns will change in a complex, spatially non-uniform way.

Based on climate modelling done for the IPCC 5th assessment report, and recent work presented in the IPCC special report on 1.5 degrees (IPCC, 2018), limiting warming to 1.5°C above preindustrial levels will require rapid, historically unprecedented mitigation efforts (Millar *et al.*, 2017). Applying a different, statistical modelling approach found below 2°C warming at the end of the 21st century unlikely, and requiring a much accelerated decline in carbon intensity compared to the past decades (Raftery *et al.*, 2017). By 2050, in the RCP2.6 pathway, CO_2 emissions are projected to be lower than they were in 1990. Projected atmospheric concentrations range from ca. 440 ppm (RCP2.6) to ca. 540 ppm (RCP8.5) by 2050 to ca. 420-935 ppm by 2100, but uncertainties are of several tens/hundreds of ppm.

Land-use change

Land-use and land-cover changes have direct and large impacts on the physical environment. They include expansion of crops and pastures, as well as intensification and management changes, mineral and biomass extraction, urbanization and infrastructure expansion (Geist & Lambin, 2002). Eitelberg *et al.* (2015) estimated the global potential for crop area to range from ca. present-day expanse (1500 Mha) to nearly a tripling (5100 Mha), depending on different future socio-economic and governance assumptions. Synthesising projected future crop, pasture and forest areas, Alexander *et al.* (2017c) showed a huge spread in projected future land-use change, and found that this spread depended on the type of scenario, as could be expected, but also was heavily dependent on the type of model used to quantify land use for a given scenario (i.e. the same scenario archetype results in very different land-use change patterns depending on the underlying model's assumptions and structure). Overall, these studies suggest that there remains a high level of uncertainty in future land-use change potential and in scenarios of land-use change.

The five main SSP storylines that have been developed in support of the IPCC can be classified by archetypes **(Table 4.1.2)**, but considerable caution should be exercised when interpreting land-use projections from the SSP storylines as being representative of a particular archetype. For example, the largest declines in global area of forest and other natural land occur in the reference scenarios (also referred to as "marker scenarios") for SSP3, SSP4 and SSP5 (Popp *et al.*, 2017), i.e. scenarios that emphasise competition or free markets. However, the range of variation of the projected change in managed land area by 2100 is nearly as large within SSPs (i.e. variation due to application of different IAMs to the same SSP storyline) as it is between marker scenarios across SSPs (Popp *et al.*, 2017). Given this large variation within SSPs and high uncertainty in land-use projections identified by Alexander *et al.* (2017c), considerable caution must be exercised when making the connection between the underlying assumptions of scenario archetypes **(Tables 4.1.1 and 4.1.4)** and an individual projection of land use by a single Integrated Assessment Model (e.g., **Figure 4.1.3**).

In the wake of the Paris COP21 agreement, terrestrial ecosystems will make crucial contributions to meeting agreed climate mitigation objectives. Achieving the RCP2.6 pathway (or the most recent RCP1.9 pathway, see IPCC, 2018) requires, in nearly all scenarios developed with IAMs, negative emissions through carbon-dioxide removal. The majority of this is generally achieved through reforestation, afforestation and avoided deforestation, as well as bioenergy plantations coupled with carbon capture and storage (Anderson & Peters, 2016; Smith *et al.*, 2016). Depending on how fast fossil fuel emissions decline, substantial negative emissions to balance continued fossil emissions need to be achieved by 2050, or even earlier (Anderson & Peters, 2016) which, if implemented, will have large consequences for terrestrial ecosystems. Recent results indicated that SSPs 1, 2, 4 and 5 might be consistent with low greenhouse gas emissions (i.e., RCP2.6; Kriegler *et al.*, 2014; Popp *et al.*, 2017) (see also examples in **Figure 4.1.3**). Despite the very different assumptions contained in the SSPs (and in the IAMs simulating these) there is consistent projected decline in food crop and pasture area at the end of the 21st century, even though demand for crop and livestock products tend to be larger than today. At the same time, area under bioenergy plantation increases by between ca. 200 Mha (SSP1/AIM) and 1500 Mha (SSP4/GCAM4).

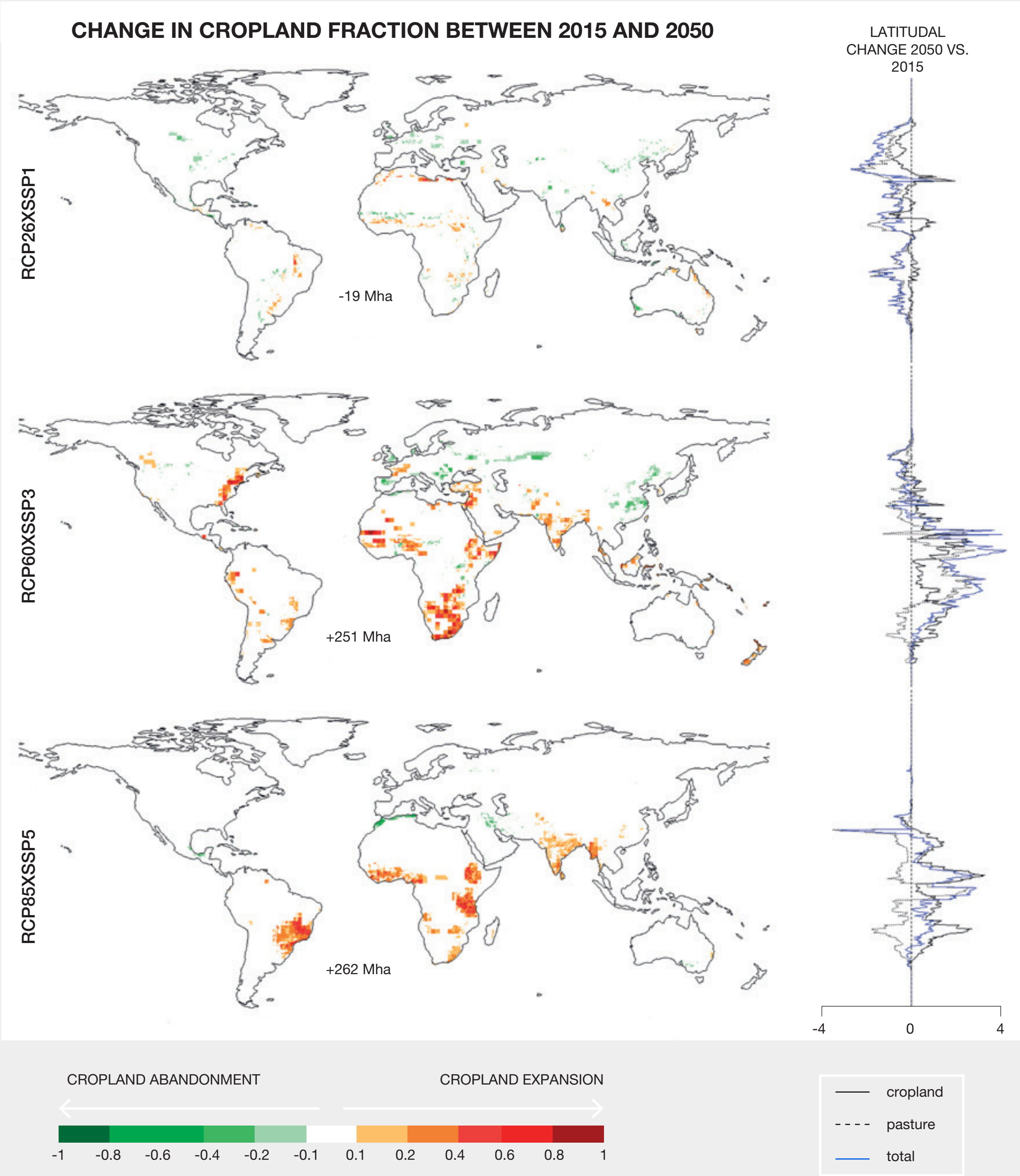


Figure 4 1 3 **Projected changes in cropland area used in the Biodiversity and Ecosystem Services Model Intercomparison Project (BES-SIM, Kim *et al.*, 2018; see box 4.2.5).**

Note that the depicted projections are from a single Integrated Assessment Model per SSP and may not be representative of the range of land-use projections for archetypes to which the SSP is assigned **(Table 4.1.2)**. For instance, trends in agricultural area used by Krause *et al.* (2017, 2018) for their RCP2.6 baseline case were opposite (increasing agricultural area) to the trends seen in the scenario RCP2.6/SSP1 used in BES-SIM. A map with cropland as well as pasture area changes is provided in Appendix 4.1 (Figure A4.1.12).

The intensity of land-use change can be as important as the change in area. In particular, the productivity of croplands is assumed to increase in the future as a result of increased application of technology, including the use of fertilizers, high producing varieties, machinery and pesticides. Intensification has huge impacts on biodiversity in agricultural landscapes, where for example species richness reduces by more than 50% in intensively used croplands, compared to low input systems (e.g., Newbold *et al.*, 2015). Intensification will continue in the coming decades and a recent analysis for the SSP scenarios showed trade-offs between land-use change and intensification **(Table 4.1.6)**.

To meet the demand of a growing and wealthier population, increased agricultural production results from land conversion to cropland in the SSP3/RCP6.0 and SSP5/RCP8.5 scenarios and from intensification in all scenarios, where in SSP3/RCP6.0 scenario a relatively low increase of the yield is assumed.

Pollution

Pollution here refers to solid and chemical waste of various kinds, excluding the gases referenced in the Kyoto and Montreal Protocols. Large increases in waste generation have occurred in the past decades, with a particular challenge for persistent organic pollutants (POPs) and synthetic organic polymers (plastics) which are physically harmful, chemically toxic, and slow to metabolize (see 4.2.2.4.1). Solid waste generation rates depend strongly on urban population growth trends, together with changing standard of living and societal efforts towards waste reduction. On current trends, waste production will attain 11 Mt day^{-1} by 2100, and will continue to rise into the latter half of this century particularly in sub-Saharan Africa (Hoornweg *et al.*, 2013). However, socio-economic pathways could strongly affect waste production trends, with SSP1 stabilising global waste production by about 2070 at roughly 8.5 Mt day^{-1} relative to values of 12 Mt day^{-1} in SSP2 and SSP3 (Hoornweg *et al.*, 2013).

Direct harvesting of natural resources

Scenarios relating to direct harvesting will have complex relationships with distinct socio-economic futures. In terrestrial ecosystems, while an increase in human wealth may reduce direct harvesting of provisioning resources (such as bushmeat), increasing wealth may increase demands for some traditional (e.g. medicinal) and "luxury" (e.g. Rhino horn) resources. On the other hand, marine and freshwater natural resources might undergo increased fishing pressure in the face of rising affluence and continuous growth of human population that is projected to reach 9.8 billion people by 2050 (UNDESA, 2017). Scenarios of governance in fisheries management, human consumption of seafood, improvement of fishing technology (Squires & Vestergaard, 2013) are starting to be integrated into future global scale projections (section 4.2.2.3).

Invasive Alien Species

Invasive alien species (IAS) are those that have been moved by direct human actions beyond their native geographic range, and have established and actively expand geographic range after introduction (Blackburn *et al.*, 2014). The main impacts of socio-economic scenarios on IAS are likely to be through vectors for dispersal (with international trade and long-distance transport being the most important), and economic resources to combat IAS. Higher impacts are thus to be expected under future scenarios of greater global trade with weaker local governance.

Quantification of the impacts of IAS tends to focus on adverse ecological effects (Simberloff *et al.*, 2013), including adverse impacts on ecosystem services. It is thus difficult to develop a fully integrated understanding of positive, neutral and negative impacts, though current consensus strongly suggests overall adverse impacts (Pyšek & Richardson, 2010). For example, invasive plants can cause catastrophic regime shifts and indigenous diversity reduction (Gaertner *et al.*, 2014), such as through N-fixing species increasing N concentrations in nutrient-poor soil (Blackburn *et al.*, 2014), and by increasing fire frequencies and intensities, or even introducing novel fire regimes (Pausas & Keeley, 2014).

Table 4 1 6 **Changes in global cropland area and productivity increase for three SSP scenarios, as analysed in a model comparison study by BES-SIM.**

	SSP1/RCP2.6	SSP3/RCP6.0	SSP5/RCP8.5
Cropland in 2015 in km²	15885409	15885409	15885409
Cropland in 2050 in km²	15696191	18399153	18507559
Cropland area increase 2015-2050 %	-1.2	15.8	16.55
Crop production increase 2015-2050 %	31.7	40.5	58.4
Yield increase 2015-2050 %	33	21	36
Yield increase per year %	0.95	0.61	1.03

Invasive animals may cause extreme indigenous diversity loss particularly if they are predators and invade in islands (Medina *et al.*, 2011).

The number of documented IAS is most probably a significant underestimate of the true number, partly because of inadequate research effort particularly in some developing countries with potentially high IAS densities (McGeoch *et al.*, 2010). The IUCN Red List Index indicates that the adverse impacts of IAS include increased rates of decline in species diversity (McGeoch *et al.*, 2010).

Disturbance

Disturbance is a fundamental driver of biodiversity, and ecosystem structure and function, and may strongly control ecosystem services delivered. Almost all ecosystems experience episodic events like floods, droughts and wildfire. Where disturbance is frequent enough, natural selection both permits nature to adapt, and some species may even become dependent on disturbance, and enhance its frequency (Parr *et al.*, 2014). A prime example is wildfire, which is of global significance in that it is an important factor in determining local to landscape scale ecosystem structure over vast areas of the subtropics and tropics. Without fire, ecosystem structure and function in fire-prone regions may alter their biodiversity, structure and function entirely (Bond *et al.*, 2005). Many plant species are designed to accelerate fire frequency and intensity (Keeley *et al.*, 2011). Disturbance is thus an important tool available in the management of biodiversity, ecosystem structure and function, and the ecosystem services that result (Folke *et al.*, 2004). Disturbance is likely to be most strongly affected by climate (especially in case of fire) as well as socio-economic scenarios. Fire, droughts and flooding would be expected with higher frequency under low future climate change mitigation scenarios. However, for fire it has been argued that changes in human population density, and shifts in urban to rural lifestyles affect future burnt area to the same degree as climate change, through reducing fire spread (Knorr *et al.*, 2016). However, as more people are projected to live in fire-prone areas, potentially detrimental impacts on societies may nonetheless increase (Knorr *et al.*, 2016).

4.1.5 Considering Indigenous Peoples and Local Communities (IPLCs) and indigenous and local knowledge (ILK) in scenarios

The integration of indigenous and local knowledge (ILK) into scenarios developed at the regional and global scales, as well as the assessment of the impacts of scenarios on Indigenous Peoples and Local Communities (IPLCs), have been limited and remain a key challenge in scenario development (Hill *et al.*, 2012; Wohling, 2009). Varying combinations of indirect drivers, and especially government policy, can disproportionately impact IPLCs and their livelihoods. This is particularly significant when considering scenarios as alternative policy or management options intended to alter the future state of these (system) components (IPBES, 2016b). The following examples provide evidence for the potential benefits that could be gained from a better recognition of and respect for ILK and IPLCs in conservation of nature, as well as adaptation to and mitigation of climate change.

Government policies that (i) define agro-industrial plantations as forests, (ii) change property systems, including privatization and land titling over areas of customary tenure, and (iii) incentivize migration to historically low population density areas, undermine ILK that promote biodiversity and human well-being, and traditional land-use practices (Dressler *et al.*, 2017).

Some cases where governments have recognized IPLC land rights and pursued climate mitigation policies, such as through REDD+ projects (Reducing Emissions from Deforestation and Forest Degradation), have led to thus-far successful collaborations and demonstrated that ILK could make significant contributions to future forest and biodiversity conservation (see also review in chapter 6). For instance, the case of GuateCarbon, which incorporates the Association of Forest Producers of Petén (ACOFOP, in northern Guatemala) as full partners alongside government entities and international NGOs, has proved a potentially important model for negotiation, benefit sharing, and monitoring, reporting, and verification that respects local land-use practices and values (Hodgdon *et al.*, 2013). Positive livelihood outcomes have accompanied a pattern of strong forest protection in areas with community-led management here.

Studies suggest that policy scenarios such as protected area designation – including territorial recognition for IPLCs – could play a significant role in avoiding future deforestation, such as in the Amazon, despite continued pressures to downgrade, downsize, and degazette protected areas (PADDD) for infrastructure development and more intensive land uses (Forrest *et al.*, 2015; Soares-Filho *et al.*, 2010). For example, a recent Brazilian moratorium on mega-dams – long demanded by indigenous groups on ecological and spiritual grounds – could enhance ecosystem protection, especially if accompanied by increased support for forest groups (Branford, 2018), despite continuing plans for inter-modal transport projects essentially promoting agro-industry and colonization (Molina *et al.*, 2015). While the Brazilian Amazon has served as an important testing ground for recognizing the importance of ILK in forest management and for REDD+, the continued discounting of ILK systems in broader land-use policy throws doubt on the long-term viability of such participative initiatives (Cromberg *et al.*, 2014; Vitel *et al.*, 2013). Specific major drivers vary by country and by region, but global demand for basic commodities and national enabling environments for investment in forest-rich countries will likely continue to contribute to terrestrial emissions and biodiversity loss – including through incursions on IPLCs' traditional lands and the attendant loss of ILK. Thus, even where REDD+ and conservation initiatives have tried to ensure community participation, they achieve variable success, in part because they often fail to address the strongest indirect drivers of losses of forests, biodiversity and ecosystem services (Angelsen *et al.*, 2017).

Notwithstanding these limits, the long period of negotiation over the program internationally and nationally, in addition to a pivot away from market-based approaches implementation, has provided IPLCs with opportunities to insert their priorities (tenure security, Free, Prior and Informed Consent, social services) into the debate (Angelsen *et al.*, 2017; Van Dam, 2011). Increasing rates of recognition of IPLCs' rights to inhabit and manage their lands alongside new sources of dedicated funding (such as the UNFCCC's Green Climate Fund) could suggest stronger outcomes for avoided deforestation and ecosystem health.

4.2 PLAUSIBLE FUTURES FOR NATURE

4.2.1 Impacts of future global changes on biodiversity: feedbacks and adaptation capacity

4.2.1.1 Projected negative changes at all levels of biodiversity

The scientific community has focused on climate change as a major driver of concern in exploring possible futures for nature **(Table 4.2.1)**. Based on our systematic literature review (Appendix A4.1.1), 88% of the global scenario literature addressed climate change impacts on nature, followed by 8% and 2% of the papers addressing land-use change and natural resource extraction, respectively. A vast majority of the papers addressed single drivers, as few integrated models are able to represent combination of drivers and interactions are more complex to implement (IPBES, 2016b). Of all the scenarios exploring climate change impacts, only 18% were combined with other direct drivers of change such as land use or natural resource extraction.

Table 4 2 1 **Major drivers represented in global change scenarios addressing impacts on nature at global scale, across terrestrial, freshwater and marine ecosystems.**

The number of scenarios published is reported, and in parentheses, the number of scientific papers from the Chapter 4 literature database (Appendix A4.1.1). Scenarios addressed single drivers (purple cells) or combination of drivers.

	Climate change	Invasive alien species	Land-use change	Natural resource extraction	Pollution	Others
Climate change	569(270)	4(3)	104(36)	12(6)	8(4)	11(8)
Invasive alien species		10(2)				
Land-use change			45(19)	7(4)	4(2)	1(1)
Natural resource extraction				16(7)	1(1)	
Pollution					1(1)	1(1)
Others						27(8)

Most scenarios of biodiversity change are terrestrial or marine, while far fewer exist for freshwater (**Figure 4.2.1**; IPBES, 2016b). Therefore, most evidence provided in section 4.2.3 for freshwater biomes is based on local and regional studies. Overall, relatively few metrics of biodiversity and ecosystem function have been explored deeply enough to draw strong conclusions about their interactions in a globally changing environment.

The systematic literature review indicates that the effects of global environmental changes on biodiversity are mostly projected to be negative **(Figure 4.2.1)** and embrace all biodiversity levels – from genetic diversity to biomes (Bellard *et al.*, 2012; **Box 4.2.1**). Marine systems are projected to be generally more negatively impacted by global change drivers than terrestrial systems **(Figure 4.2.1)**. For example, projected changes in species biomass or abundance cover the spectrum of negative to positive trends in terrestrial systems (see evidence provided in sections 4.2.4.1 to 4.2.4.4), but negative trends stand out in marine systems (see section 4.2.2). There are a few metrics, such as terrestrial C pools or organisms' growth, where positive trends are the most common response in the literature (see 4.2.4.1). In case of C-pools this reflects chiefly the impact of CO_2 on photosynthesis and growth, which in some models outpace the impacts of warming. In boreal and temperate regions, climate change was also shown to possibly have positive effects on organisms' growth, e.g., plant growth (Pretzsch *et al.*, 2014). All other metrics of biodiversity and ecosystem function are dominated by projected neutral or negative trends in response to projected global change drivers. Negative trends are particularly dominant for indicators of production, reproduction success, terrestrial species richness and extinction, marine species biomass and abundance, and the area and quality of marine habitats.

Figure 4 2 1 **Future trends of selected indicators in marine A, terrestrial B and freshwater ecosystems C, based on global scale scenarios referenced in the literature database (Appendix A4.1.1), all drivers combined.**

The results are extracted from scenarios with increasing pressures from direct drivers (all climate change scenarios and business-as-usual scenarios for resource exploitation, land-use change and pollution). The selected scenarios were at global scale. Regional/local scale scenarios were not referenced in the literature database. Colours code the projected trends in the indicators. N=the number of trends reported and in parentheses the number of papers.

A substantial fraction of wild species is predicted to be at risk of extinction during the 21st century due to climate change, land use and impact of other direct drivers (Bellard *et al.*, 2012; Pimm *et al.*, 2014; Settele *et al.*, 2014; see sections 4.2.2-4.2.4). In a recent review of published future global extinction risk, Urban (2015) found that extinction risk is projected to increase from 2.8% at present to 5.2% at the international policy target of a 2°C post-industrial rise, to 8.5% if the Earth warms to 3°C, and to 16% in a high greenhouse gas emissions scenario (RCP 8.5; 4.3°C rise). Extinctions might not occur immediately but after substantial delay called because when a population has been reduced to very small numbers, it has a high risk to go extinct at some point in the future (referred to as «extinction debt»). This means that long-term effects of global change can be much more severe than short term impacts (Cronk *et al.*, 2016; Dullinger *et al.*, 2012; Fordham *et al.*, 2016; Hylander & Ehrlén, 2013).

Notwithstanding a majority of expected negative impacts of future climate change on biodiversity, **Figure 4.2.1** suggests the potential for some positive effects in species distributions areas and species richness. General poleward movement of marine and terrestrial species and upward movement of terrestrial mountain species may lead to increase in local species richness in high latitudes and in mountainous regions, while the opposite is projected in the tropics and flat landscapes (Gilg *et al.*, 2012; Jones & Cheung, 2015; Settele *et al.*, 2014; Thuiller *et al.*, 2014).

Global scale scenarios can mask the spatial heterogeneity of projected biodiversity response at finer scales (Urban, 2015; Vellend *et al.*, 2017). For example, the highest species extinction risk due to climate and land-use changes is projected in the tropics and polar regions as well as in top mountain habitats because of projected "novel" climates in tropics that these regions have never experienced in the past (Mora *et al.*, 2013a), narrow physiological tolerances of tropical and polar species, expected disappearance of polar and top-mountain habitats (Deutsch *et al.*, 2008; Gilg *et al.,* 2012; Mora *et al.*, 2013a; Pörtner *et al.*, 2014; Settele *et al.*, 2014) and the highest risk of conversion of ecosystems to crops and biofuel in the tropics (Kehoe *et al.*, 2017; Newbold *et al.*, 2015). Biodiversity hotspots are also projected as subject to high species extinction (Bellard *et al.*, 2014; see 4.2.2, 4.2.3, 4.2.4).

To account for the spatial differentiation of global changes impacts on nature, the following sections 4.2.2, 4.2.3, and 4.2.4 cover the outcomes of the literature database analysis (Appendix A4.1.1), but also include detailed examination of key studies and specific biomes (IPBES units of analysis). The major drivers of change and the primary impacts differ depending on the biome considered **(Figure 4.2.2)**, and therefore need to be addressed by specific, and sometimes local, adaptation and mitigation policies.

4.2.1.2 Future biodiversity adaptation and reorganisation

Species can respond to environmental changes in many different ways that are not mutually exclusive. In response to changes in climate, species can adapt to new conditions, they can shift their geographical distribution following optimal environmental gradients or can go locally extinct.

A large number of scenarios explore ***species distribution shifts***. Terrestrial species may respond to climate changes by shifting their latitudinal and elevation ranges. Marine species may respond by shifting their latitudinal and depth ranges. Models predict latitudinal range shifts for plant and animal species of hundreds of km over the next century as well as significant range contraction and fragmentation (Leadley *et al.*, 2010; Markovic *et al.*, 2014; Meller *et al.*, 2015; Rondinini & Visconti, 2015; Warren *et al.*, 2013). Comparisons of projected climate velocity (the rate of movement of the climate across a landscape) and species displacement rates across landscapes showed that many terrestrial species (e.g., plants, amphibians, and some small mammals) will be unable to move fast enough to track suitable climates under medium and high rates of climate change (i.e. RCP4.5, RCP6.0, and RCP8.5 scenarios). Most species will be able to track climate only under the lowest rates of climate change (RCP2.6) (Settele *et al.*, 2014). Natural geographical barriers (Burrows *et al.*, 2014) and human-made habitat disruptions are predicted as important factors limiting movement of species ranges (Meier *et al.*, 2012; Schloss *et al.*, 2012).

Species adaptation to novel conditions is likely to mitigate the predicted impacts of global changes (Hoffmann & Sgrò, 2011; Lavergne *et al.*, 2010; Neaves *et al.*, 2015; Pauls *et al.*, 2013; Skelly *et al.*, 2007). Models that ignore adaptation may overestimate extinction probabilities. For example, the inclusion of local adaptations due to phenotypic plasticity and microevolution in models of terrestrial carnivore and ungulate species decreases the expected decline in population abundance by 2050, from 31–34% to 18% (Visconti *et al.*, 2016; see **Box 4.2.1**)

Intraspecific diversity of behavioral, phenological, physiological and morphological traits allows populations and species to survive under rapid climate change through standing genetic variation (GD1 in **Box 4.2.1**), and provides material for selection in new conditions (Alfaro *et al.*, 2014; Hof *et al.*, 2011; Jump *et al.*, 2009). On the one hand, incorporating intraspecific variation in species models increases the likelihood of their survival as shown for several tree species (Benito Garzón *et al.*, 2011; Morin & Thuiller, 2009; Oney *et al.*, 2013). On the other hand, projections that do not consider probable loss of intraspecific diversity can underestimate future negative effects on biodiversity. The loss of genetic diversity is projected for a number of

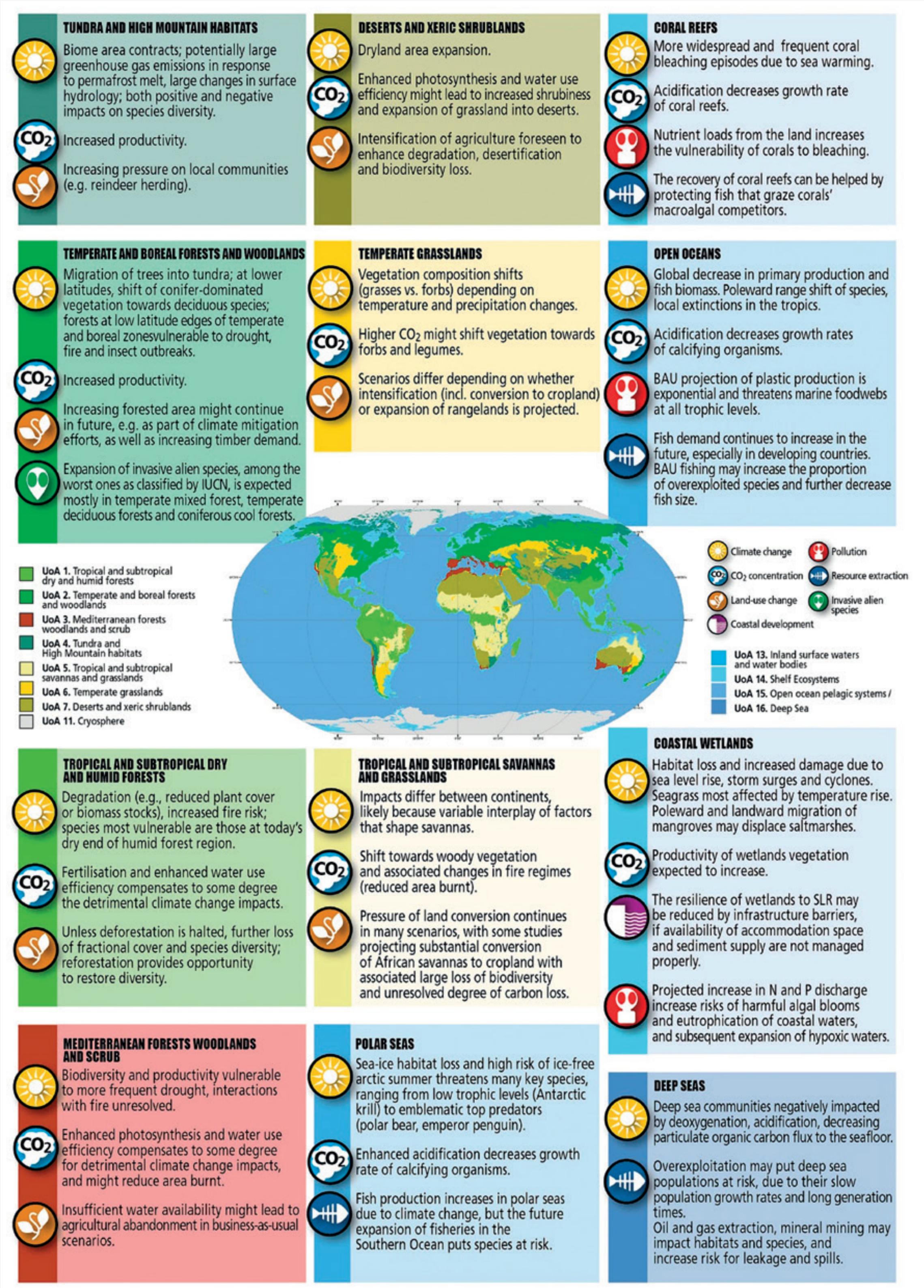


Figure 4 2 2 **Examples of future projected impacts of major drivers of change on nature (supporting evidence in sections 2.2 and 2.4 of the chapter, and Table A4.2.1 in Appendix 4.2).**

Examples are given for IPBES terrestrial and marine units of analysis (UoA).

species belonging to very different terrestrial and aquatic taxa and thus, should be recognized as a serious threat to future biodiversity rescue (Bálint *et al.*, 2011; Jump *et al.*, 2009; Neaves *et al.*, 2015; Pauls *et al.*, 2013).

Phenotypic plasticity helps to reduce the risk of species extinction (GD2 in **Box 4.2.1**) allowing a rapid (within individual's lifetime) adjustment of populations to novel conditions whereas evolutionary responses require several generations (Chevin *et al.*, 2010). Incorporating phenotypic plasticity in models predicting future species' distributions reduced the extinction risk in southern populations of several species (Benito Garzón *et al.*, 2011; Morin & Thuiller, 2009).

Rapid adaptive evolution (GD3 in **Box 4.2.1**) occurring at similar time scale as global environmental change has the potential for "evolutionary rescue", i.e. population survival *in situ* due to ongoing selection of standing genetic variations as well as relatively slower selection of new mutations (Gonzalez *et al.*, 2013; Hendry *et al.*, 2011; Hoffmann & Sgrò, 2011; Settele *et al.*, 2014). However, evolutionary responses may be too slow for species with low capacity for adaptive evolution, especially under large-scale and rapid environmental changes (Gienapp *et al.*, 2012; Jump *et al.*, 2006).

Adaptation can cascade to entire communities or ecosystems, thus maintaining community properties beyond the level of change in the driver. However, adaptive capacity is not unlimited and so even evolving systems can eventually switch to a new state if a change in a driver is too severe or too rapid. Return to the original system state when change pressure is removed to the original state can be harder than would have been the case without evolution, due to the depletion of the genetic variation **(Figure 4.2.3)**.

Along with the vital importance of preserving the short-term adaptive capacity of biodiversity, the necessity of *long-term maintenance of further evolutionary* processes generating biodiversity and potential future ecosystem services was recognized as a key goal that requires preservation of evolutionary heritage and phylogenetic diversity of the Tree of Life (Faith, 2015; Faith *et al.*, 2010; Forest *et al.*, 2007; Mace & Purvis, 2008).

Reorganization of ecological communities and novel communities: Substantial changes in *species composition and biotic interactions* are expected due to shifts in species distribution (S1 in **Box 4.2.1**), local species extinctions, alterations of species abundance, functioning and phenology (S2 in **Box 4.2.1**). Projected changes in species composition can lead to disruptions of food webs and mutualistic relationships, increased prevalence of pests and pathogens, introductions of alien species, biotic homogenization and loss of biological uniqueness of communities (Blois *et al.*, 2013; Buisson *et al.*, 2013; Thuiller *et al.*, 2014).

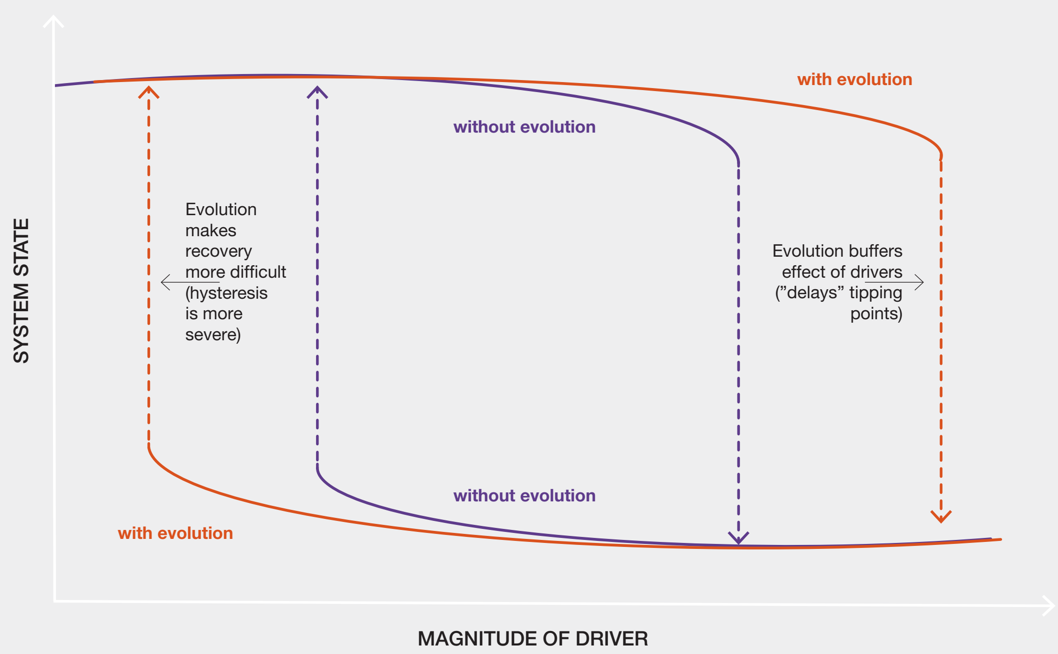


Figure 4 2 3 **Potential role of evolution (more generally, "adaptive capacity") in mediating tipping points, alternative stable states, and hysteresis.**

Novel (no-analog) communities, in which species will co-occur in historically unknown combinations, are expected to emerge (Ordonez *et al.*, 2016; Radeloff *et al.*, 2015; Williams & Jackson, 2007). Novel communities are expected to become increasingly homogeneous and shifted towards smaller size species and generalists with broader ecological niches (Blois *et al.*, 2013; Lurgi *et al.*, 2012). Novel interactions can strongly affect species fitness because species will lack a long coevolutionary history in new conditions (Gilman *et al.*, 2010; see also Appendix 4.2).

4.2.1.3 The importance of feedbacks between hierarchical levels of biodiversity

Some well described feedbacks between different hierarchical levels and facets of biodiversity are self-reinforcing and could likely amplify negative effects of global changes on biodiversity (Brook *et al.*, 2008). Integration of processes acting at different organizational biodiversity levels is essential for future predictions of global change impacts on nature (Mouquet *et al.*, 2015; Thuiller *et al.*, 2013).

The feedback between population size and genetic diversity (S4 in **Box 4.2.1**) is known as an extinction vortex (Frankham *et al.*, 2014) because the reduction in population size leads to the loss of genetic diversity which in turn, leads to decrease in population fitness and adaptability and further reduction in population size. The *feedback between species' range and genetic diversity* (S5 in **Box 4.2.1**) means that the contraction and fragmentation of species ranges are expected to cause genetic loss through decrease in effective population size and extinction of genetic lineages as well as extinction of local populations with unique genetic characteristics (Bálint *et al.*, 2011; Pauls *et al.*, 2013). Genetic loss, in turn, may decrease species adaptability and migration capacity. The *feedback between species composition and genetic diversity* (SD3 in **Box 4.2.1**) means that changes in species composition alter the selection pressure affecting genetic diversity. For example, reduction in pollinator abundance could lead to selection favoring self-fertilization in plant populations, leading to a decrease in genetic diversity (Neaves *et al.*, 2015). Introductions of alien species may result in hybridization, out-breeding depression and decrease in genetic diversity of native species. However, hybridization may also facilitate adaptation to novel environments (Hoffmann & Sgrò, 2011). Changes in genetic diversity, in turn, contribute to further disturbance of species relationships.

The *feedback between species composition and single species extinctions* (SD4 in **Box 4.2.1**) make changes in species composition and single-species extinctions modify the web of interactions at the community level and lead to cascading and catastrophic co-extinctions called "chains of extinction" (Bellard *et al.*, 2012; Brook *et al.*, 2008). The loss of key species as well as invasions and proliferation of pests and pathogens can have the most drastic effects. Failing to account for changes in biotic interactions could cause models to under- or overestimate extinction risks (Gilman *et al.*, 2010). The *feedback between species composition and species' capacity to track climate change* (SD5 in **Box 4.2.1**) implies that interspecific interactions can modulate the outcome of species range shifts. Mutualistic interactions, such as plant-pollinator relations, may fail in tracking fast environmental change (Lavergne *et al.*, 2010). Competition and predation can both hamper and facilitate range shifting (Holt & Barfield, 2009; Svenning *et al.*, 2014). Interactions can slow climate tracking and produce more extinctions than predicted by models assuming no interactions (Urban *et al.*, 2013). Moreover, interspecific interactions can modulate the direction of species range shifts, for example, species may shift downslope due to competitive release at the lower margin of species distribution (Lenoir *et al.*, 2010). Changes in species distribution, in turn, contribute to further changes of species composition. The *feedback between landscape homogenization and species extinctions* (ED2 in **Box 4.2.1**) involves that predicted biotic homogenization and loss of biological uniqueness of communities within a region (Blois *et al.*, 2013; Buisson *et al.*, 2013; Thuiller *et al.*, 2014) can synchronize local biological responses to disturbance across individual communities and thus, compromise the potential for landscape- and regional-level disturbance buffering (Olden, 2006). Taxonomic homogenization of communities can reduce resistance of a landscape to future invasions (Olden, 2006). As a result, local extinctions of native species and invasions of alien species should be expected that, in turn, will contribute to further biotic homogenization (for details, see Appendix 4.2).

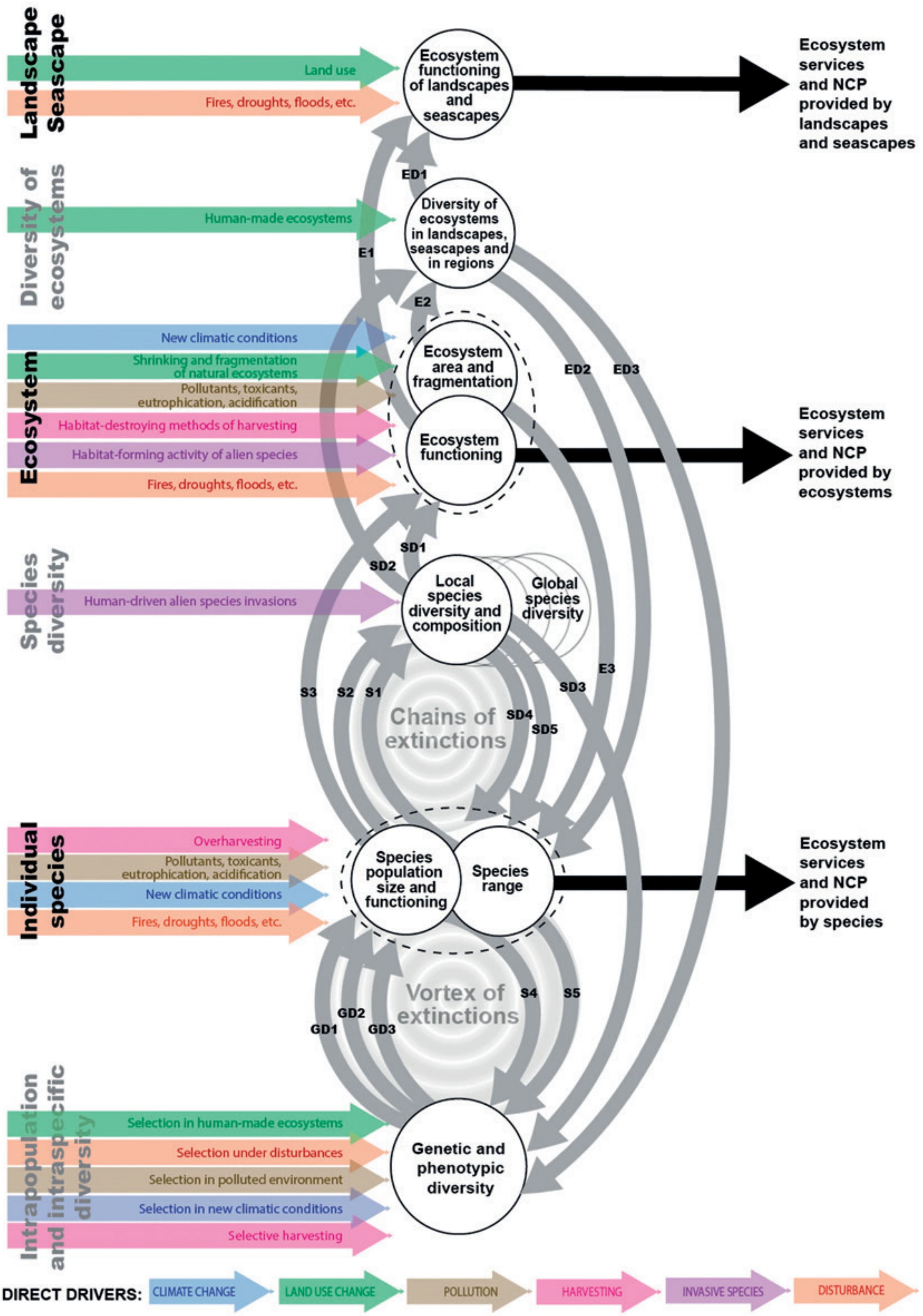
4.2.2 Marine ecosystems

4.2.2.1 Global state and function of marine ecosystems and future drivers of change

The ocean is central to regulating the Earth's climate. The ocean absorbs around 25% of the anthropogenic emissions of CO_2 (Le Quéré *et al.*, 2016), leading to ocean acidification with a decrease in surface seawater pH of 0.1 units since the beginning of the industrial era (Orr *et al.*, 2005). The ocean absorbs 93% of the Earth's excess heat energy, resulting in warming of 0.11°C per decade in the upper 75m of the ocean between 1971 and 2010 (Rhein *et al.*, 2013). ***Oceans are essential to life and provide major services to human societies.*** Marine phytoplankton produce about half of the global O2 (Pörtner *et al.*, 2014). The ocean supports fisheries and aquaculture activities and produced on average 104.3 million tons

Box 4 2 1 The main interrelations and feedbacks between hierarchical levels that are important for the future of biodiversity.

Direct drivers of global change affect all levels of biodiversity, either directly (coloured arrows) or indirectly through feedbacks (grey arrows). Even one-way interactions are important for biodiversity response, while self-reinforcing feedbacks can potentially significantly increase expected negative effects of global change drivers (for details, see Appendix 4.2).



Effects of changes in genetic and phenotypic diversity
GD1 – adaptation of populations to new conditions through standing genetic and phenotypic variations
GD2 – adaptation of populations due to phenotypic plasticity
GD3 – adaptive evolution, "evolutionary rescue" of populations and species

Effects of changes in functioning, population size and range of individual species
S1 – changes in local species composition due to alteration of species range (shift, change in area, fragmentation)
S2 – changes in local species composition due to local species extinctions and alteration of species abundance and functioning (including changes in phenology)
S3 – changes in ecosystem structure and functioning due to changes in key species abundance and functioning
S4 – changes in genetic diversity due to changes in population size
S5 – changes in genetic diversity due of alteration in species range (shift, change in area, fragmentation) and dispersal ability

Effects of changes in local species diversity, species composition and interspecific relations
SD1 – weakening and destabilization of ecosystem functioning due to loss of local species diversity
SD2 – biotic homogenization as a result of species shift, local species extinctions and invasions
SD3 – changes in selection pressure because of alteration of species composition and interspecific relations (including effects of alien species invasions)
SD4 – species extinctions as a result of cascading effects of alteration of species composition
SD5 – impact of alteration of species composition on species capacity to track climate change

Effects of changes in structure and functioning of ecosystems
E1 – the contribution of individual ecosystems to the total landscape/seascape ecosystem functioning
E2 – disappearance of the most vulnerable ecosystems in landscapes/seascapes and regions
E3 – reduction of species population size, reduction and fragmentation of species' ranges and disruption of population structure because of habitat loss and fragmentation

Effects of changes in diversity of ecosystems, heterogeneity of landscapes and seascapes
ED1 – weakening and destabilization of the total landscape/seascape functioning because of loss of ecosystem/habitat diversity
ED2 – influence of landscape heterogeneity on local species persistence
ED3 – influence of landscape heterogeneity on genetic diversity and evolution

per year of fish and invertebrates from 2009-2014, which represented approximately 17% of the animal protein consumed by humans (FAO, 2016). Oceans supports rapid socioeconomic development and growth of human population on coastlines, with increasingly intensive, multiple uses leading to heavily degraded habitats (Spalding *et al.*, 2014; Wong *et al.*, 2014). ***Marine populations and communities have been impacted at unprecedented rates*** by climate change (mainly in the form of ocean warming, ocean acidification, deoxygenation, and sea level rise) and direct anthropogenic activities (mainly in the form of fishing, pollution, and habitat degradation) (Chapter 2; Hoegh-Guldberg *et al.*, 2014; Poloczanska *et al.*, 2016; Pörtner *et al.*, 2014).

Globally, none of these pressures are projected to decrease in the future. Earth System Models have been used to project future environmental conditions (IPCC, 2013), showing that the state of the future ocean will strongly depend on the amount of carbon emitted in the coming decades (Gattuso *et al.*, 2015; IPCC, 2018). Climate change is, among other drivers, the main driver considered in global scale scenarios **(Table 4.2.2)**.

Mean sea surface temperature is projected to increase by +2.7°C in 2090-2099 as compared to 1990-1999 for the high emission scenario (RCP8.5), whereas the warming is limited to +0.71°C for the more stringent RCP2.6 emission scenario (Bopp *et al.*, 2013); model-mean values from the Coupled Model Intercomparison Project 5). At the regional scale, stronger warming occurs in the tropics, in the North Pacific and in the Arctic Ocean, with the sea surface warming more than +4°C at the end of the 21st century under RCP8.5 (Bopp *et al.*, 2013; Collins *et al.*, 2013).

As global temperatures rise, so does the **mean sea level** due primarily to the thermal expansion of ocean water and by melting of glaciers, ice caps and ice sheets. A sea level model calibrated with empirical data and forced by the IPCC high emission scenario (RCP8.5) projects a sea level rise (SLR) of 52-131 cm by 2100 relative to year 2000 (Kopp *et al.*, 2016).

A broadly uniform decrease of the **mean sea surface pH** of -0.33 pH units (model-mean) by the 2090s relative to the 1990s is predicted under RCP8.5 (Bopp *et al.*, 2013), which is accompanied by a decrease in carbonate ion concentration and in the saturation states of calcium carbonates (e.g., calcite, aragonite), essential components of shells or skeletons of many marine organisms. The volume of undersaturated waters with respect to aragonite is projected to increase between 1990 and 2100 from 76% to 91% of the global ocean under RCP8.5 (Gattuso *et al.*, 2015).

Earth system models also project **decreasing global ocean oxygen** due to climate change. The mechanisms at play are a reduction of oxygen solubility due to ocean warming and the combination of increased stratification and reduced ventilation that prevents the penetration of oxygen into the deep ocean (Breitburg *et al.*, 2018). Deoxygenation will continue over the 21[st] century irrespective of the future scenario, with decreases of global O_2 of -1.8% and -3.45% (model-mean) under RCP2.6 and RCP8.5, respectively (Ciais *et al.*, 2013), with a stronger drop for the North Pacific, the North Atlantic, and the Southern Ocean (Bopp *et al.*, 2013). Despite a consistent global deoxygenation trend across models, there is as yet no consensus on the evolution of hypoxic and suboxic

Table 4 2 2 **Major climate-related and direct human-mediated drivers of change impacting marine ecosystems (by IPBES subunits) as highlight in this chapter's sections 4.2.2.2 to 4.2.2.5.**

Cells are colored when there is substantial evidence from the reviewed scenarios and models that drivers have a major impact on one of the marine ecosystems. Where the information exists, the second column of the table reports the percentage of marine global scale scenarios implementing changes in the drivers and quantifying impacts on nature, based on our literature database (Appendix A4.1.1).

Direct drivers of change	Global scale	Open ocean pelagic	Polar seas	Shelf ecosystems					Deep sea ecosystems
				Tropical coral reefs	Rocky and sandy shores	Mangrove forests	Seagrass meadows	Kelp forests	
Climate-related drivers of change									
Ocean warming	45%								
Ocean acidification	8%								
Deoxygenation	4%								
Sea ice melt	2%								
Sea level rise (SLR)	16%								
Extreme events	3%								
Direct human-mediated drivers of change									
Fishing	16%								
Pollution	5%								
Maritime transport									
Species introduction									
Land-use change	1%								
Coastal development	1%								
Aquaculture									
Oil and gas extraction, mineral mining									
Main direct impacts on nature									
Habitat degradation									
Biodiversity decline									
Species invasion / range shift									
Shifts in food webs and biogeochemical cycles									
Eutrophication									
Hypoxia									

waters due to uncertainties in potential biogeochemical effects and in the evolution of tropical ocean dynamics (Cabré *et al.*, 2015). Along coastlines, deoxygenation and the increase of hypoxic "dead zones" are largely driven by direct human activities (which combine with sea warming), with rivers draining large nitrogen and phosphorus loads from fertilized agricultural watersheds, and from sewage, aquaculture and atmospheric nitrogen deposition, causing eutrophication and subsequent aerobic microbial decomposition (Glibert *et al.*, 2018; Levin *et al.*, 2009; Rabalais *et al.*, 2009).

Future climate change will hence alter marine habitats and modify biogeochemical cycles. Recent modelling work has shown that climate change may continue to produce more hostile conditions and threaten vulnerable ecosystems and species with low adaptive capacity (Gattuso *et al.*, 2015; Hoegh-Guldberg *et al.*, 2014; Mora *et al.*, 2013a; Pörtner *et al.*, 2014; Wong *et al.*, 2014).

Adding to future climate change and potentially amplifying impacts on marine ecosystems, direct human-mediated pressures will likely intensify in future. An **increase in fisheries and aquaculture production** is plausible as a response to increasing demand for fish and seafood (Chapter 11 of the World Ocean Assessment, UN, 2017) which is expected to arise as a result of population growth and increasing average income that allows for augmenting the proportion of fish in the diet (World Bank, 2013). Under assumptions of increasing technological efficiencies and increasing demand for fish, the FAO and OECD project that total world marine seafood production (fishery plus aquaculture) would exceed 120 million tons in 2025, or plus 17% relative to 2013-2015. Diverse forms of **pollution** (excessive nutrient loads, toxic contaminants, persistent organic pollutants, plastics, solid waste) will likely continue to pervade marine ecosystems in the future, constituting additional threats to living organisms (Bergman *et al.*, 2012; Geyer *et al.*, 2017; Lamb *et al.*, 2018; Sutton *et al.*, 2013; Worm *et al.*, 2017). The oceans are sinks for landborne and airborne inputs of persistent pollutants which can both travel great distances in the near-surface water masses (Eriksen *et al.*, 2014) of the open ocean, and sink into the deeper ocean (Chapter 20 of the World Ocean Assessment, UN, 2017). In coastal oceanic waters, increasing nutrient loads and pollution in combination with warming will likely stimulate eutrophication and increase the extent of oxygen minimum zones (Breitburg *et al.*, 2018; Rabalais *et al.*, 2009).

The impacts of global change on marine biodiversity will vary geographically, with latitudinal gradients of expected in many global scale scenarios (Gattuso *et al.*, 2015), and depending on the type of ecosystems **(Table 4.2.2)**. Major drivers of change in the open ocean pelagic ecosystems that are included in global scale models and scenarios are climate-related drivers (sea warming, acidification, deoxygenation), and fisheries exploitation. Additional future threats included in scenarios for shelf ecosystems are sea level rise, extreme events, nutrient pollution and coastal development which may cause degradation, fragmentation and loss of habitats **(Table 4.2.2)**.

Future scenarios of climate change impacts on marine biodiversity at global scales are the most documented in the literature (78% of the scenarios in our literature database – **Table 4.2.2**). They will therefore form the main content of this section (section 4.2.2.2), with evidence provided by type of ecosystems (IPBES units of analysis). The rest of the drivers are much less, or not at all, represented in scenarios projecting impacts on marine biodiversity at global scale, even though their historical and current impacts on biodiversity have been shown to be significant. Moreover, there are relatively few global scale scenarios involving multiple pressures on marine ecosystems and biodiversity (23% of the marine scenarios involve a combination of multiple drivers in our global scale literature database), so in addition to updating recent global assessments with the latest modelling and scenarios work, sections 4.2.2.2 to 4.2.2.5 report evidence from more local studies of how direct anthropogenic drivers may combine with climate change in impacting future marine biodiversity.

4.2.2.2 Future climate change impacts on marine biodiversity and ecosystem functioning

4.2.2.2.1 Climate change impacts in open ocean ecosystems

Low trophic levels

Net Primary Production (NPP) by marine phytoplankton is responsible for 50% of global carbon fixation through photosynthesis, but is also the basis of marine food webs, controlling the energy and food available to upper trophic levels. Earth System Models project a mean decrease of NPP in 2100 under all RCP greenhouse gas emissions scenarios, ranging from -3.5% to -9% under RCP2.6 (low emissions) and RCP8.5 (very high emissions), respectively (Bopp *et al.*, 2013), though there is significant variation between individual model projections. The global decrease of NPP is accompanied by a change in the seasonal timing of peak NPP, with an advance by ~0.5–1 months by 2100 globally, particularly pronounced in the Arctic (Henson *et al.*, 2013).

The projections are heterogeneous over space with general agreement that NPP is expected to decrease in the tropics and in the North Atlantic, and increase at high latitudes (Bopp *et al.*, 2013; Boyd *et al.*, 2014; Steinacher *et al.*, 2010). Some regional discrepancies between models exist, with nonlinear dynamics making some projections uncertain. In the tropics, the mechanisms at play are largely model-dependent, with both stratification–driven reduction in nutrient availability and increases in grazing and other phytoplankton loss processes (Laufkötter *et al.*, 2015). This results in large inter-model differences, with the decline in tropical NPP being projected between -1 and -30% by 2100 under RCP8.5 (Kwiatkowski *et al.*, 2017). Using satellite-based observations of ocean–colour and an emergent-constraint relationship, the uncertainties in the decline of tropical NPP have been reduced with an estimated decline of -11±6% in 2100 for a business-as-usual scenario (Kwiatkowski *et al.*, 2017).

In the Arctic, some models project an increase in NPP because of the loss of perennial sea-ice and an increase of light availability, whereas other models simulate a decrease due to increasing ocean stratification and decreasing nitrate availability (Vancoppenolle *et al.*, 2013). In the Southern Ocean, models project a zonally-varying response of NPP to climate change, with a decrease in the subpolar band (50°S and 65°S), but increases in the Antarctic (south of 65°S) and in the transitional band (40°S-50°S) (Leung *et al.*, 2015). Mechanisms at play are changing light availability and iron supply by sea ice melting (Wang *et al.*, 2014).

Under the SRES A1B scenario, the reduction in zooplankton biomass was projected to be higher than for primary production in 47% of the ocean surface particularly in the tropical oceans, implying negative amplification of ocean warming through bottom-up control of the food web (Chust *et al.*, 2014). This impact differs regionally with positive amplification of zooplankton biomass in response to the increase of NPP in the Arctic and Antarctic oceans, thereby increasing the efficiency of the biological pump in those regions. Other changes in species composition can be expected under future climate change, such as shifts from diatom-dominated phytoplankton assemblages with high POC export efficiencies to smaller, picoplankton communities characterized by low export efficiencies (Morán *et al.*, 2015; Smith *et al.*, 2008).

In addition to warming and changes in ocean stratification/circulation, ocean acidification is also expected to influence metabolic processes in phytoplankton and zooplankton species. Laboratory and mesocosm experiments have shown contrasting responses for different plankton types under elevated CO_2 concentrations, with a stimulating influence for nitrogen-fixing cyanobacteria (Hutchins *et al.*, 2007, 2013) and pico-eukaryotes (Bach *et al.*, 2017), but potential detrimental effects on growth and calcification rates for some of the main calcifying phytoplankton (Meyer & Riebesell, 2015). Other potential effects of ocean acidification include a reduction in microbial conversion of ammonium into nitrate (Beman *et al.*, 2011), which could have major consequences for oceanic primary production and potentially less carbon export to the deep sea. A recent modeling study incorporating differing growth responses of phytoplankton types to increased pCO_2, has suggested that acidification effects may even outrank the effects of warming and of reduced nutrient supply on phytoplankton communities over the 21st century (Dutkiewicz *et al.*, 2015).

Higher trophic levels

Most published global scale scenarios of change in higher trophic levels in response to climate change rely on correlative models examining changes in species' spatial distribution (64% of publications on the effect of climate change on marine biodiversity at global scale in our literature database*,* Appendix A4.1.1). These "Species Distribution Models" (SDMs) (also called ecological niche models or climate envelope models) analyze the statistical relationship between species occurrences and a set of environmental variables (Araújo & New, 2007; Thuiller *et al.*, 2009). SDMs do not typically consider species adaptation nor the effects of species interactions.

Using species distribution models for projecting future climate-induced changes, the main findings at the global scale are that species will shift their distribution poleward (Cheung *et al.*, 2009), likely resulting in an increase in species richness and species invasions in high latitude regions (the Arctic and Southern Ocean) and conversely a decrease of species richness in the tropics and the equator (García Molinos *et al.*, 2016; Jones & Cheung, 2015; Pörtner *et al.*, 2014) and in semi-enclosed seas (e.g., Mediterranean Sea, Ben Rais Lasram *et al.*, 2010). A mean latitudinal range shift of 25.6 km per decade to 2050 was projected under the high emission scenario RCP8.5, which reduced to 15.5 km per decade under RCP2.6 (Jones & Cheung, 2015).

Distributional shifts of marine species are the most clearly detectable pattern that can currently be assigned to climate change, or more specifically to sea surface temperature change (García Molinos *et al.*, 2016). This is related to the sensitivity of marine ectotherms, which constitute the bulk of high trophic level species, to temperature change. But ocean warming can trigger additional adaptive responses such as phenological shifts and physiological changes in growth and reproduction. It is expected that animals inhabiting temperate latitudes, where seasonality is strong, will better adapt to a changing climate whereas polar stenotherm species will be more vulnerable to warming (Pörtner *et al.*, 2014). Tropical species, in addition to having narrow thermal windows, inhabit the warmest waters and are thus near physiological temperature tolerance limits that lower their adaptive capacity (Storch *et al.*, 2014)
At low latitudes, open-ocean oxygen-minimum zones (OMZ) constitute an additional threat to marine organisms, especially in the eastern tropical Pacific (Cabré *et al.*, 2015)

and along major eastern boundary upwelling systems (Gilly *et al.*, 2013). The horizontal and vertical expansion of already large OMZs will potentially affect marine populations dramatically, through shifts in their spatial distribution and abundance, as well as altered microbial processes and predator-prey interactions (Breitburg *et al.*, 2018; Gilly *et al.*, 2013). The shoaling of the upper boundary of the OMZs can also trap fish in shallower waters, compressing their habitat, and thereby increasing their vulnerability to predation and fishing (Bertrand *et al.*, 2011; Breitburg *et al.*, 2018).

In addition to correlative species distribution models, there are recently developed integrated modelling approaches (e.g., end-to-end models combining the physics of the ocean to organisms ranging from primary producers to top predators) considering the multiple responses of marine populations to climate change (based on e.g., physiological rates, trophic interactions, migration behavior), as well as essential food web knock-on effects and adaptive mechanisms to move towards more realistic projections of marine biodiversity (Payne *et al.*, 2016; Rose *et al.*, 2010; Stock *et al.*, 2011; Tittensor *et al.*, 2018a; Travers *et al.*, 2007). At regional and local scales, such models have been developed with more detailed representation of multiple taxa of commercial interest or of conservation concern than at the global scale, where the few existing end-to-end models represent ecosystems and biodiversity through large functional groups (e.g. fish biomass, pelagic biomass, biomass in different size classes) or are focused on single key species. A global scale end-to-end model run under the worst-case scenario (RCP8.5) projected that the biomass of high trophic level organisms would decrease by 25% by the end of the century (Lefort *et al.*, 2015). This first estimate, which has been recently confirmed by an ensemble of global marine ecosystem models **(Box 4.2.2)**, suggests that the response of high trophic levels amplifies the decrease of biomass projected for phytoplankton and zooplankton.

Global scale models project that ocean warming may shrink the mean size of fish by the end of century (Cheung *et al.*, 2013; Lefort *et al.*, 2015) and lead to smaller-sized infaunal benthos globally (Jones *et al.*, 2014). This trend is very robust to the model used in the different studies, as well as to the mechanisms involved: the decrease in mean size could be either due to the combined effects of future warming and deoxygenation on animal growth rates (Cheung *et al.*, 2013), the combined effects of warming and food limitation (Lefort *et al.*, 2015), or to the limiting flux of particulate organic matter from the upper ocean to the benthos (Jones *et al.*, 2014).

Air-breathing marine species

Marine turtles are particularly vulnerable to climate change as, being ectotherms, their behavior, physiology, and life traits are strongly influenced by environmental factors (Janzen, 1994; Standora & Spotila, 1985). Arguably, the most detectable impacts will occur during the terrestrial reproductive phase: incubating eggs are vulnerable to sea-level and extreme weather events (Fish *et al.*, 2005; Fuentes *et al.*, 2010), while future changes in temperature and rainfall at nesting beaches will likely reduce hatching success and emergence, cause a feminization of turtle populations, and produce hatchlings with higher rates of abnormalities (Fisher *et al.*, 2014; Mrosovsky & Yntema, 1980). Future changes in temperature are expected to impact the frequency and timing of nesting (Fuentes & Saba, 2016; Limpus & Nicholls, 1988; Saba *et al.*, 2007), as well as marine turtle distribution (McMahon & Hays, 2006; Pikesley *et al.*, 2015; Witt *et al.*, 2010). Foraging specialists (i.e. leatherbacks) might be more susceptible to climate change impacts on the marine food web relative to foraging generalists (i.e. loggerheads) due to a lesser ability to switch prey type (Fuentes & Saba, 2016). Ultimately, impacts will depend on populations' resilience and ability to adapt. Some marine turtle populations are already responding to climate change by redistributing their nesting grounds and shifting their nesting phenology (Pikesley *et al.*, 2015). However, it is still unclear whether marine turtles will be able to fully adapt since climatic changes are occurring more rapidly than in the past and are accompanied by a variety of anthropogenic threats (e.g., fisheries by-catch, pollution) that make them more vulnerable and decrease their resilience (Fuentes *et al.*, 2013; Poloczanska *et al.*, 2009).

Seabirds responses to future climate change are commonly predicted using species distribution models. Shifts and contractions in foraging habitat could be particularly problematic for seabirds by increasing energetic expenditures. For example, the summer foraging areas for king penguins are predicted to shift southward in response to an intermediate warming scenario (SRES A1B), doubling the travel distance to optimal foraging areas for breeders with likely negative consequences for population performance (Peron *et al.*, 2012). Poleward shifts in foraging areas are also projected for seven Southern Ocean albatross and petrel species under a range of emission scenarios, with associated range contractions of up to 70% for wandering and grey-headed albatross by 2050 (Krüger *et al.*, 2018). For other species (e.g., the endangered Barau's storm petrel), climate-driven shifts and contractions in wintering range are predicted but the overall population consequences are unclear (Legrand *et al.*, 2016). Fewer studies have coupled mechanistic population models with climate projections to estimate future population trajectories. Cassin's auklets are predicted to decline by 11-45% by 2100 under a mid-level emission scenario, due to increased sea surface temperatures and changes in upwelling dynamics within their foraging range (Wolf *et al.*, 2010). Contrasting responses to future climate scenarios were reported in three seabirds (albatrosses and petrel),

Box 4 2 2 Ensemble model projections of marine ecosystem futures under climate change.

Model intercomparison studies use a common set of input conditions to force a suite of potentially very different models to then produce an 'ensemble' of outputs. These outputs can be compared to examine differences among models, and provide a multi-model mean and range of uncertainty for end users. While such studies are a common tool in the Earth system and climate modelling communities, their application to biodiversity and ecosystems, particularly in the marine realm, remains relatively new.

Fish-MIP (Tittensor *et al.*, 2018b) is the first model intercomparison project examining the impacts of climate change on fisheries and marine ecosystems at regional to global scales using a common set of climate change scenarios. There have been many different attempts to model the ocean ecosystem resulting in a large diversity of models with various purposes – from examining species distributions to ecosystem structure to fisheries catch potential (Tittensor *et al.*, 2018b). Fish-MIP provides a common simulation framework and standardized forcing variables to provide consistent inputs to these models and prescribes a common set of consistent outputs for analysis. In the first round of Fish-MIP, the focus was on examining climate change (rather than fisheries) both regional and global scales. Here, marine animal biomass includes mostly fish, but in some models, invertebrates and marine mammals are also considered.

The results across six global marine ecosystem models (APECOSM, BOATS, DBEM, DPBM, EcoOcean, Macroecological) that were forced with two different Earth-system models (ESMs) and two emission scenarios (RCPs 2.6 and 8.5) show that ocean animal biomass will likely to decline over the coming century under all climate change scenarios (Figure 4.2.4; Lotze *et al.*, 2018; Tittensor *et al.*, 2018b). The ensemble model means show steeper declines under RCP8.5 (highest emission scenario) than RCP2.6 (high mitigation scenario), and steeper declines when forced with the ESM IPSL-CM5A-LR than GFDL-ESM2M. The trajectories from different ESMs and RCPs remain relatively similar until about 2030 to 2050, after which they begin to diverge markedly. Thus, by 2100, the model-mean animal biomass is projected to decline between 3% and 23% **(Figure 4.2.4)**. These declines are largely driven by a combination of increasing water temperature and declining primary productivity, and are likely to impact ecosystem services including fisheries (Blanchard *et al.*, 2017).

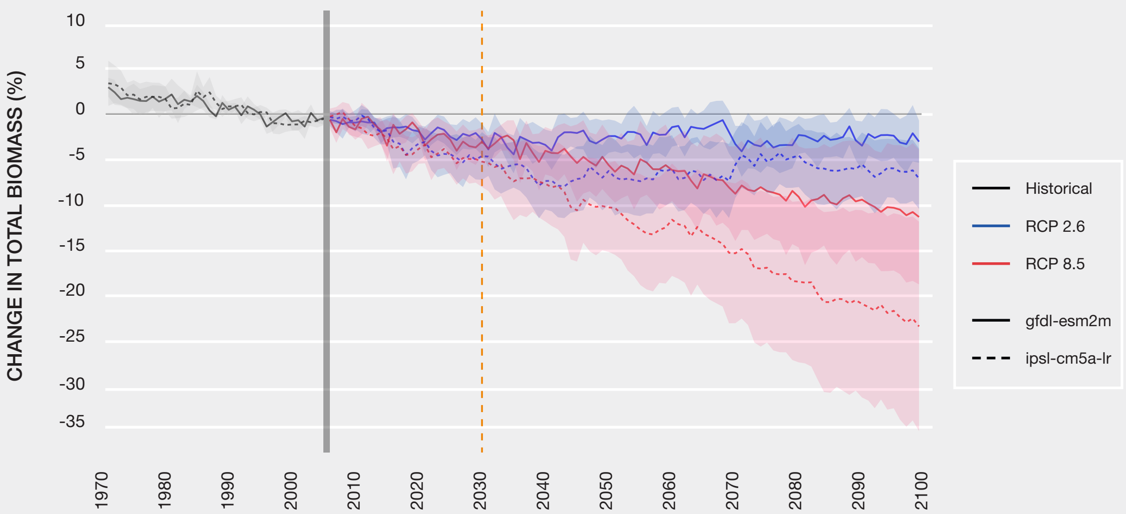


Figure 4 2 4 **Ensemble projections of global ocean animal biomass under different scenarios of climate change.**

Projections represent the multi-model means of six global marine ecosystem models forced by marine environment change projected by two different Earth-system models: GFDL-ESM2M (solid lines) and IPSL-CM5A-LR (dashed lines) and two greenhouse gas emission scenarios: RCP2.6 (low emissions; blue) and RCP8.5 (very high emission; red) with no fishing signal imposed (i.e., changes are due only to climate). Shaded areas represent one inter-model standard deviation (ecosystem models). All percentage changes are relative to a 1990-1999 baseline. The vertical grey line separates historical and future projections for climate forcing; the vertical dashed orange line represents the 2030 target year for the Sustainable Development Goals. Data source: Tittensor *et al.* (2018b); Lotze *et al.* (2018).

Spatial maps of ensemble projections (**Figure 4.2.5**; Lotze *et al.*, 2018; Tittensor *et al.*, 2018b) show broad-scale decreases in animal biomass in tropical and many temperate regions, and potential increases in polar regions. While ensemble projections across many models are more likely to capture plausible trends than any single model, there was more variation among models in polar and some coastal regions, suggesting that there is greater uncertainty about projected outcomes.

The results shown here for global marine ecosystem models are helpful for describing the global trends but may not capture the complex dynamics at local and regional scales. Forthcoming analyses should therefore compare regional projections based on regional scale models and global models and examine the variability between regional models to provide projections and measures of uncertainty at scales better matched to the needs of resource managers. Moreover, different scenarios of fishing pressure need to be incorporated to examine interactions between fishing and climate change impacts.

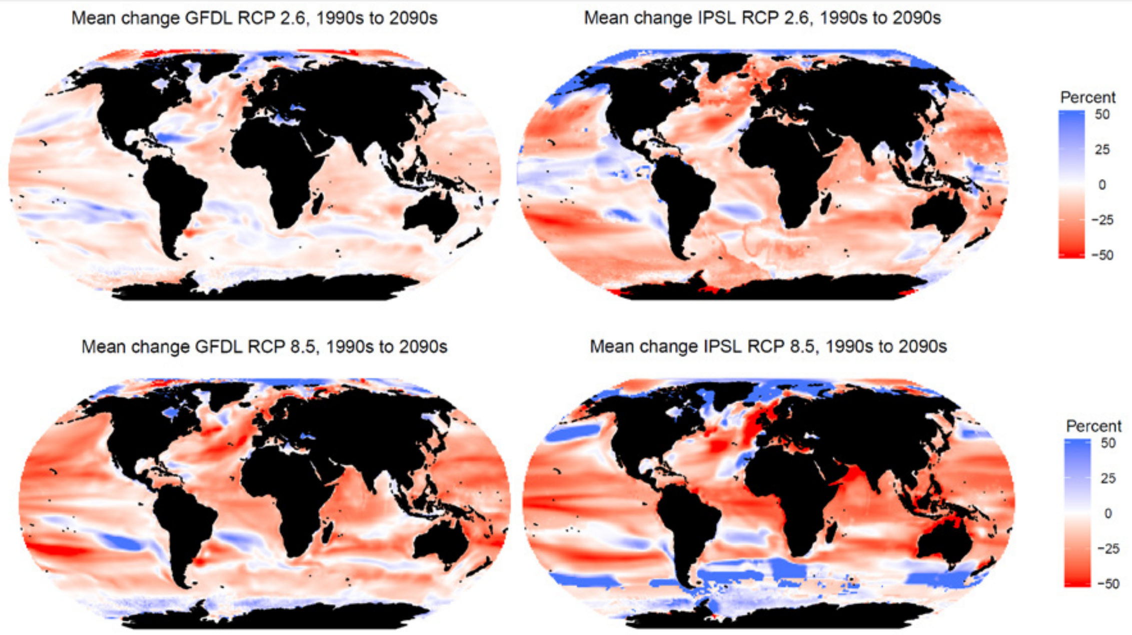


Figure 4 2 5 **Global ensemble mean spatial patterns of change in global ocean animal biomass under RCP2.6 (low greenhouse gas emissions; top) and RCP8.5 (very high emissions; bottom) forced by GFDL-ESM2M (left) and IPSL-CM5A-LR (right) Earth System Models.**

Percentage changes are relative to a 1990-1999 baseline. Data source: Tittensor *et al.* (2018b); Lotze *et al.* (2018).

owing to differences in life histories and distribution area (Barbraud *et al.*, 2011). These studies have identified strong non-linearities in demographic responses, suggesting the potential for threshold effects under future climate extremes (Pardo *et al.*, 2017).

Marine mammals, as homeotherms, are physiologically buffered from some direct effects of temperature rise. Rising ocean levels from ocean warming and ice melt will likely lead to a loss of land or ice-based habitat available for breeding or pupping, particularly for marine mammals on low-lying atolls or ice-dependent breeders (Baker *et al.*, 2006; Laidre *et al.*, 2015). A global assessment of climate change effects on marine mammals used a range of climate scenarios (warming between 1.1°C and 6.4°C) to qualitatively rank negative population effects for all marine mammal species (MacLeod, 2009). It showed that species tied to land, ice, or facing geomorphic barriers were most likely to be affected.

4.2.2.2.2 Climate change impacts in shelf ecosystems

Tropical Coral Reefs

An unprecedented 3-year (2014-2017) marine heat wave have damaged most of coral reefs on Earth (75%) with still unassessed social-ecological consequences (Eakin *et al.*, 2018). Thermal stress disrupts the relationship between corals and their algal symbionts, with bleached corals being physiologically damaged and suffering severe mortality rate. The number of years between recurrent severe coral-bleaching events has diminished fivefold in the past four decades, from once every 25 to 30 years in the early 1980s to once every 5.9 years in 2016 (Hughes *et al.*, 2018). A full recovery of mature coral assemblages, source of reef biodiversity and productivity, generally takes from 10 to 15 years for the fastest growing species (Hughes *et al.*, 2018). Many reefs, including those of the iconic and well-protected Great Barrier Reef, have experienced a shift from dominance of branching tabular species that build 3-dimensional habitats, towards corals with simpler morphological characteristics (Hughes *et al.*, 2018). A trophic model showed that a loss of coral complexity could cause more than a 3-fold reduction in fishery productivity (Rogers *et al.*, 2014), due to the preferential settling of juvenile fishes in unbleached coral habitat (Scott & Dixson, 2016).

In addition to thermal stress, ocean acidification represents a major threat to marine calcifier organisms like corals, particularly those building large but low-density skeletons. A decrease of pH by 0.4 units (expected under RCP8.5; Hoegh-Guldberg *et al.*, 2014) would translate into a coral habitat complexity loss of 50%, inducing a decrease in species richness by 30% for both fish and invertebrates (Sunday *et al.*, 2017). A seawater pH lowered by just 0.14 units (RCP2.6) would induce a loss of 34% net community calcification (Albright *et al.*, 2018). Projections anticipate a shift from a state of net accretion to net dissolution before the end of the century (Eyre *et al.*, 2018). Anoxic events are also rapidly increasing in prevalence worldwide and cause underestimated mass mortality on coral reefs (Altieri *et al.*, 2017).

To better anticipate and simulate the potential futures of coral reef habitats, two complementary approaches have been used. First, laboratory and field experiments try to estimate the tolerance, acclimatization and adaptability of coral species and their symbionts to environmental changes. One of the most striking studies demonstrates that progressive acclimatization, even to temperatures up to 35°C, can achieve the same heat tolerance as expected from strong natural selection over many generations (Palumbi *et al.*, 2014). This suggests that at temperatures beyond the thermal limits of coral species, the rate and speed of temperature change is key to explain coral bleaching. Experiments also allow testing of the interactions of multiple stressors. For instance, a 3-year field experiment deciphered the mechanisms by which elevated temperatures exacerbate overfishing and nutrient pollution effects on corals by increasing coral–algal competition and reducing coral recruitment, growth and survivorship (Zaneveld *et al.*, 2016).

Second, models attempt to simulate the futures of tropical coral reefs under various scenarios. A simulation based on genomic models predicting future evolution and persistence in a high-latitude population of corals from Cook Islands (South Pacific) showed a rapid evolution of heat tolerance resulting in population persistence under mild warming scenarios (RCP2.6 and RCP4.5) though this adaptation would not be rapid enough to prevent extinction under more severe scenarios (RCP6.0 and RCP8.5; Bay *et al.*, 2017). Other studies based on niche models, that can also integrate adaptation capacity related coral cover to environmental variables allowing for projections at global (Logan *et al.*, 2014) and regional (Ainsworth *et al.*, 2016) scales. For instance, coral cover on the Great Barrier Reef was projected to remain lower than 5% before the end of the century under a high emission scenario (RCP8.5) (Ainsworth *et al.*, 2016).

Rocky and sandy shores

Straddling the intersection between land and ocean, rocky and sandy shores are the dominant components of coastlines globally, are the most accessible of the marine biomes and supply services in terms of coastal protection, direct provisioning (food and materials), recreation (tourism, fishing), spiritual and cultural purposes, and substrate for aquaculture and infrastructure.

These ecosystems are vulnerable to sea-level rise which adds to the height of sea-level extremes, such as during storm surges, and can exacerbate projected changes in wave impacts (Hemer *et al.*, 2013). Sea level rise can affect the dynamics of the morphology of beach systems, as well as increasing coastal inundation risk, leading to erosion in many cases, as well as increasing threats to nesting beaches for turtles and seabirds, dune vegetation and coastal infrastructure and assets (e.g., de Winter & Ruessink, 2017; Jevrejeva *et al.*, 2016; Pike *et al.*, 2015).

Evidence of species responses to warming oceans are recorded from sandy and rocky shores globally, showing that barnacles, mollusks, crabs and macroalgae have shifted their distributions in response to recent warming (e.g., Johnson *et al.*, 2013; Pitt *et al.*, 2010; Poloczanska *et al.*, 2013; Schoeman *et al.*, 2015; Wethey *et al.*, 2011). For example, the cold-water barnacle *Semibalanus balanoides* may disappear from south-western English shores by 2050 (Poloczanska *et al.*, 2008). The frequency of temperature extremes is projected to increase in the next few decades, particularly during summer in regions such as the Mediterranean (Kirtman *et al.*, 2013), with potential high ecosystem impact as large-scale mortalities of intertidal species have been recorded during extreme heat events (Garrabou *et al.*, 2009; Wernberg *et al.*, 2013). In south-east Australia, the temperature-driven range extension of the sea urchin *Centrostephanus rodgersii* has led to the loss and overgrazing of kelp beds and a reduction in associated biodiversity (Johnson *et al.*, 2011; Ling *et al.*, 2015).

Forests of kelp, large brown temperate-coast marine algae, are themselves directly impacted by climate change. Under RCP2.6 and RCP8.5 scenarios, models of kelps in the

North Atlantic incorporating changes in temperature, salinity, and sea ice cover predict northern movement and range contraction by 2090 (Assis *et al.*, 2017a, 2017b, 2016; Raybaud *et al.*, 2013). Under RCP8.5, areas such as the Gulf of Maine, Southern Europe, and the northwestern coast of Africa would be bereft of kelps (Assis *et al.*, 2017a), a trend which in some of these systems is already observed now (Filbee-Dexter *et al.*, 2016; Krumhansl *et al.*, 2016). The Arctic, conversely, is projected to gain kelps, which is consistent with observations of kelp increases in areas that are decreasing in sea-ice cover and hence increasing in light availability (Bartsch *et al.*, 2016). The area gained is not projected to counterbalance the area lost. Similarly, in Japan, models project its southernmost species, *Ecklonia cava*, to colonize new northern habitats that are currently occupied by colder water kelps, due to a combination of shifting temperatures and increases in grazing by warm water fishes under all RCP scenarios by 2090. Further scenario-based modeling efforts are needed for Australia, New Zealand, the Southern Atlantic, and the Pacific Coasts of the Americas, where models of climate change's future impacts on kelps have been less explored. While modeled predictions typically report declines or polar movement, the observed long-term trajectories of kelp forests are currently mixed (Krumhansl *et al.*, 2016). In some cases, such as South Africa, this is due to local cooling (Blamey *et al.*, 2015; Bolton *et al.*, 2012). In others, climate driven range expansions of urchin predators has also driven local increases (Fagerli *et al.*, 2014), although the longevity of this trend is unclear as they can be overridden by physical drivers (Moy & Christie, 2012).

Coastal wetlands

Coastal wetlands are found along coastlines globally, and include salt marshes (mostly found along temperate, boreal and arctic coastlines), mangroves (mostly found in tropical and subtropical areas), tidal flats, and seagrasses. They form essential marine vegetated habitats for carbon sequestration, and coastal protection against increased sea level rise (SLR) and natural hazards (Alongi, 2008; Duarte *et al.*, 2013; Fourqurean *et al.*, 2012). They also host a great diversity of species, playing a major role as nursery and breeding areas for a wide variety of marine fauna organisms (Heck Hay *et al.*, 2003), including migratory ones such as coastal birds (Nuse *et al.*, 2015) or coral reef fish species (Harborne *et al.*, 2016). Climate changes in the form of warming, sea level rise and increased extreme events (e.g. hurricanes) may increase the vulnerability of these ecosystems in the future. Vegetated coastal habitats are already declining globally (Duarte *et al.*, 2005), and many species are threatened with extinction (Polidoro *et al.*, 2010; Short *et al.*, 2011). The recent IPCC report on « Global warming of 1.5°C » (IPCC, 2018) assessed that at global warming limited to 1.8°C above the pre-industrial level, the risks to mangroves will remain medium (e.g., not keeping pace with SLR; more frequent heat stress mortality) whereas seagrasses are projected to reach moderate to high levels of risk (e.g., mass mortality from extreme temperatures, storm damage) (Hoegh-Guldberg *et al.*, 2018).

Sea level rise can have large impacts on coastal ecosystems because of the flat, gentle slope of much coastal land. Although coastal wetlands are dynamic ecosystems that can adapt to sea level rise, their capacity to do so is limited, regionally differentiated and is affected by many human activities (Kirwan & Megonigal, 2013; Schuerch *et al.*, 2018; see 4.2.2.5). The response of wetlands to sea level rise involves landward migration of vegetated areas, and submergence at lower elevations (Wong *et al.*, 2014). Acceleration of sea level rise threatens future wetlands capacity to adapt with occurrence of horizontal retreat, and vertical drowning, when accretion of sediment and organic matter cannot keep pace with SLR (Spencer *et al.*, 2016). A meta-analysis estimated that under RCP2.6, 60% of the saltmarshes will be gaining elevation at a rate insufficient to keep pace with SLR by 2100, and the loss could reach 90% under high SLR (RCP8.5) (Crosby *et al.*, 2016). Such high SLR (1m by 2100) could put at risk 68% of coastal wetlands in developing countries (Blankespoor *et al.*, 2014). By contrast, a just published integrated model, taking into account the capacity of wetlands to both expand horizontally by inland migration and build up vertically by sediment accretion, projected less pessimistic impacts of SLR with the loss of global coastal wetlands area ranging between 0 and 30% by 2100, depending on the RCP considered (Schuerch *et al.*, 2018). Sea level rise and storm surges cause salinity intrusion inland, that can impact coastal and freshwater wetlands, with various effects such as decreased inorganic nitrogen removal, decreased carbon storage, and increased generation of toxic sulphides (Herbert *et al.*, 2015). Increased salt and sulphide concentrations induce physiological stress in biota and ultimately can result in large shifts in communities and associated ecosystem functions. Because impacts of sea level rise are so prominent in coastal wetlands (Jennerjahn *et al.*, 2017), the impacts of temperature rise have been relatively less explored despite their importance in terms of ecosystem structure and function (Gabler *et al.*, 2017).

Submerged plants such as seagrass are highly impacted by temperature extremes. Warming-induced deterioration of seagrass ecosystems has been observed over recent decades in the West Atlantic, Mediterranean, and Australia, with summer temperature spikes often leading to widespread seagrass mortality (Fraser *et al.*, 2014; Jordà *et al.*, 2012; Moore & Jarvis, 2008; Short & Neckles, 1999). In the western Mediterranean Sea, a model relating mortality rates to maximum sea temperature projected that seagrass meadows may become functionally extinct by 2050–2060, under the SRES A1B emission scenario (Jordà *et al.*, 2012). Climate warming is also affecting other components of seagrass ecosystems, notably via 'tropicalization'—increasing representation of tropical species—among seagrass-associated fish communities (Fodrie *et al.*, 2009), with the potential to reduce seagrass biomass and habitat complexity as tropical herbivorous fishes increase (Heck *et al.*, 2015). Among the most serious concerns is rising frequency of disease epidemics and prevalence of pathogens, which are associated with warming in many systems, and that could trigger widespread die-offs of seagrass (Altizer *et al.*, 2013; Harvell *et al.*, 2002; Kaldy, 2014; Sullivan *et al.*, 2013).

Under elevated mean global temperatures, mangroves are expected to displace salt marshes in many areas as the limits to mangrove growth imposed by cold events decrease (Short *et al.*, 2016). Mangroves in the southeastern US have been projected to expand in area (Osland *et al.*, 2013), consistent with observed trends across five continents over the past 50 years (Cavanaugh *et al.*, 2014; Saintilan *et al.*, 2014). These projections overlook important differences among mangrove species, and also depend on mangroves' ability to successfully migrate landward (Di Nitto *et al.*, 2014), and to build up sediment or continue to receive allochtonous sediment inputs from estuarine or freshwater sources at rates apace with SLR (Lovelock *et al.*, 2015; Parkinson *et al.*, 1994). In coastal settings experiencing erosion, an expansion of mangroves is highly unlikely. On the other hand, expansion is seen in areas of accelerating sediment deposition due to upstream land-use changes (Godoy & de Lacerda, 2015). Species distribution modeling studies have projected geographically dependent shifts in community composition and species richness under climate change scenarios (Record *et al.*, 2013). While species richness is projected to increase in SE Asia, South America, eastern Australia and parts of the African coasts, it will likely decline in Central America and the Caribbean, partly linked to increased intensity and frequency of tropical storms, as well as in northern Australia (Record *et al.*, 2013).

Under increased CO_2, the productivity of wetlands vegetation (seagrass, mangrove trees, saltmarsh plants) is expected to increase in the future (Wong *et al.*, 2014). Seagrasses are likely to be among the species that perform better in a more acidified ocean, because their growth can benefit from increasing dissolved CO_2 (Koch *et al.*, 2012). This simulation result is supported by greater growth rates reported around natural marine CO_2 seeps, where seagrass sequestered considerably more carbon below-ground under acidified conditions, suggesting a possible feedback to reduce the impacts of CO_2 injection into marine waters (Russell *et al.*, 2013). However, there is limited evidence that elevated CO_2 will increase seagrass resistance to warming (Jordà *et al.*, 2012). For mangroves, increased CO_2 has been linked to variable responses in net primary productivity, with decreased NPP projected for *Laguncularia racemosa* and increased NPP for *Rhizophora mangle* (Farnsworth *et al.*, 1996; Snedaker & Araújo, 1998). Such variation may be due in part to methodological differences, but may also reflect important variations in regional conditions (McKee, 2011).

4.2.2.2.3 Climate change impacts in deep seas

The deepsea (defined here as >200m depth) covers about 60% of global ocean area and represents the largest ecosystem in the world (Smith *et al.*, 2009; Watling *et al.*, 2013), accounting for more than 95% of the volume of the Earth's oceans. Deep sea ecological processes and characteristics (e.g., nutrient cycling, productivity) underlie the healthy functioning of ocean ecosystems and provide valuable services to mankind (Thurber *et al.*, 2014).

Many observational studies have shown that present-day climate change is already impacting deep sea environments due to increased temperature (Purkey & Johnson, 2010), deoxygenation (Helm *et al.*, 2011; Keeling *et al.*, 2010; Stramma *et al.*, 2008, 2012), lowered pH of intermediate deep-waters (Byrne *et al.*, 2010), and altered particulate organic carbon (POC) flux to the seafloor (Ruhl & Smith, 2004; Smith & Stephenson, 2013). Elevated seafloor temperatures (3.7°C at the bathyal seafloor by 2100 under RCP8.5; Mora *et al.*, 2013b; Sweetman *et al.*, 2017) will lead to warming boundary currents which has the potential to massively release methane from gas hydrates buried on margins (Johnson *et al.*, 2015; Phrampus & Hornbach, 2012), especially in the Arctic, with simultaneous effects on water column de-oxygenation and ocean acidification (Biastoch *et al.*, 2011; Boetius & Wenzhöfer, 2013). Along canyon-cut margins such as those that occur in the western Mediterranean, warming may additionally reduce density-driven processes, leading to decreased organic matter transport to the seafloor (Canals *et al.*, 2006).

Climate change is also likely to increase wind-driven upwelling in eastern boundary currents, stimulating photosynthetic production at the surface (Bakun, 1990; Bakun *et al.*, 2015; Wang *et al.*, 2014). This new production may, however, decay as it sinks and increase biogeochemical drawdown of O_2. Upwelling may also bring low-O_2, high-CO_2 water onto the shelf and upper slope (Bakun, 1990; Bakun *et al.*, 2010; Feely *et al.*, 2008; Sydeman *et al.*, 2014; Wang *et al.*, 2014). The expansion of hypoxic zones is expected to affect many aspects of deep-sea ecosystem structure and function (Gooday *et al.*, 2010).

As O2 levels decline, many species of deep water octocorals (including gorgonians and pennatulaceans) which provide habitat for a diverse array of invertebrates, are expected to decrease in abundance (Buhl-Mortensen *et al.*, 2010; Etnoyer & Morgan, 2005; Murray Roberts *et* *al.*, 2009). Acidification of deep waters has been projected to negatively impact cold-water stony corals (Scleractinia), particularly in the North Atlantic (Tittensor *et al.*, 2010). Single stressors like warming will also limit tolerance windows for other stressors such as low O2 or low pH (Pörtner, 2012; Pörtner & Knust, 2007).

With the projected global reduction in the biomass of phytoplankton in the upper ocean (Bopp *et al.*, 2013; section 4.2.2.2.1), the flux of particulate organic carbon (POC) to feed open ocean seafloor communities is expected to decrease, causing potential alterations of the biomass, composition and functioning of the benthic communities. Reductions in seafloor POC flux will be most drastic in the oceanic gyres and equatorial upwelling zones, with the northern and southern Pacific Ocean and southern Indian Ocean gyres projected to experience as much as a 32–40% decline in POC flux by the end of the century (CMIP5, RCP8.5; Mora *et al.*, 2013b; Sweetman *et al.*, 2017). Recent studies have suggested that the NE Atlantic Ocean could also undergo similar reductions in POC flux (Jones *et al.*, 2014). The abyssal ocean is highly sensitive to changes in the quantity and quality of POC flux that could affect the biomass of benthic microbial and faunal biomass, and cause dramatic reductions in the sediment mixed-layer depth, benthic respiration, and bioturbation intensity (Jones *et al.*, 2014; Smith *et al.*, 2008; Sweetman *et al.*, 2017). These changes have the potential to feed back on global carbon cycling and ultimately C-sequestration (Thurber *et al.*, 2014).

4.2.2.2.4 Climate change impacts in polar seas

Rising temperatures are projected to reduce sea ice extent and volume in the Arctic and Antarctic, some of the fastest warming places on Earth (IPCC, 2013). The rapid rate at which sea ice retreats in polar seas implies major changes to be expected in the future for biodiversity and ecosystem function (Gutt *et al.*, 2015; Larsen *et al.*, 2014; Wassmann *et al.*, 2011). All components of the food webs will potentially be impacted, from phytoplankton to top predators, and from pelagic to benthic species.

Multiple lines of evidence show that ice-melting is likely to increase primary productivity in polar seas due to increased light availability, although this could be dampened by a decrease in nutrient supply due to enhanced water column stratification that is expected from warming and freshening of surface waters (section 4.2.2.2.1; Hoegh-Guldberg *et al.*, 2018; Larsen *et al.*, 2014). It has also been shown that the increased production of floating icebergs, enriched with terrigenous material, might significantly elevate nutrient levels and primary production (Smith *et al.*, 2007). However, while primary production may increase in polar seas in the future, warmer waters can cause a shift in the composition of the zooplankton community, such as the shift from *Calanus glacialis* towards dominance of the smaller, less energy-rich *Calanus finmarchicus* in Arctic waters (Kjellerup *et al.*, 2012), with potential huge consequences up the food chain. By contrast, in coastal areas, the production and transport of organic matter to the seafloor may decline because glacial meltwater and erosion of melting tundra (Węsławski *et al.*, 2011) will likely enhance water column turbidity, which results in decreased water column light levels (Grange & Smith, 2013; Sahade *et al.*, 2015). The increased sedimentation in deep coastal areas, particularly in Arctic fjords, may also smother or clog the breathing and feeding apparatus of sessile suspension-feeders (e.g., corals and sponges), induce O_2 stress, but may favour ophiuroids and capitellid polychaetes (Sweetman *et al.*, 2017; Wlodarska-Kowalczuk *et al.*, 2005).

Changes in primary production and resulting POC flux to the seafloor will have impacts on ecosystem structure and function. Elevated POC flux increases the abundance and diversity of benthic communities, the prevalence of habitat-forming taxa (sponges, benthic cnidarians), and the extension of species ranges into deeper waters (De Rijk *et al.*, 2000). It could also trigger the switch from dominance by bacteria to dominance by metazoans for processing benthic organic matter with bottom-up consequences on the food-web (Sweetman *et al.*, 2014). Changing ice regimes may also result in physical disturbance of the deep sea, as large icebergs can scour the sediment down to 400m on the Antarctic shelf, enhancing seafloor heterogeneity and creating hard substrates for sessile megafauna (Meyer *et al.*, 2015, 2016; Schulz *et al.*, 2010). In the longer term, iceberg scouring and dropstone deposition will tend to elevate diversity on regional scales through (re)colonization processes, although the immediate effect of scouring will be local elimination of many species (Gutt & Piepenburg, 2003; Gutt *et al.*, 1996; Thatje *et al.*, 2005).

Sea ice melting is also expected to impact species up the food-web, and especially those marine mammals and seabirds depending on ice as haul-outs, but future scenarios are available for just a few emblematic species. Demographic models predict that changes in Antarctic sea ice will substantially reduce the abundance of global emperor penguin (*Aptenodytes forsteri*) by 2100 under a mid-range emission scenario (Jenouvrier *et al.*, 2014), even when complex dispersal processes are included (Jenouvrier *et al.*, 2017). A high probability of extinction is foreseen for the polar bear (*Ursus maritimus*) subpopulation of southern Beaufort under SRES A1B scenario by the end of the century, due to the decrease in the cover, the duration and the thickness of sea ice (Hunter *et al.*, 2010), but low probability of extinction has been attributed for all polar bears in the Arctic (Larsen *et al.*, 2014). However, a recent study showed that the high-energy requirements of polar bears could endanger their survival in extended ice-free periods (Pagano *et al.*, 2018).

Ocean acidification is another major stressor which will be enhanced in polar regions because of the higher capacity of seawater to absorb CO_2 at low temperatures, resulting in lower pH and under-saturated waters in aragonite and calcite (Hoegh-Guldberg *et al.*, 2014; Orr *et al.*, 2005). This may impact the growth and survival of calcifying shelled organisms such as Arctic pteropods, foraminifera in the Southern Ocean, and the recruitment of Antarctic krill *(Euphausia superba)*, all of those species being essential prey species at the basis of food-webs (Kawaguchi *et al.*, 2013; Larsen *et al.*, 2014; Trathan & Hill, 2016). Adding to the negative impacts of acidification, a combination of ice retreat and changes in primary production is projected to decrease Antarctic krill suitable habitat and survival rate (Piñones & Fedorov, 2016) with potential cascading effects on their many predators (Trathan & Hill, 2016).

4.2.2.3 Future impacts of fisheries exploitation on marine ecosystems

In addition to exposure to climate change, marine animal populations will likely undergo increased fishing pressure as a result of increasing demand for fish products (World Bank, 2013) particularly in the developing world (**Figure 4.2.6**; FAO, 2016). This will largely be driven by growth of human population that is projected to reach 9.8 billion people by 2050 (UNDESA, 2017) and by income growth in low- and middle-income countries (Vannuccini *et al.*, 2018). The rate of increase in demand for fish has been more than 2.5 per cent per year since 1950 and is likely to continue in the future (HLPE, 2014). The world fish production (capture and aquaculture) was projected to increase by 17% between the base period (2013-2015) and 2025 (FAO, 2016). With the growing demand, commercial fishing activities are likely to expand to all areas of the globe.

Scenarios that include governance in fisheries management, human consumption of seafood, and advancement of fishing technologies (Squires & Vestergaard, 2013) are starting to be integrated into global scale projections. For example, a simple surplus production model applied to a set of 4713 fisheries worldwide showed that a business-as-usual fisheries management scenario would increase the proportion of overexploited populations by ca. 30% in 2050 (Costello *et al.*, 2016). In contrast, in a scenario where long-term economic benefits are optimized, such as through rights-based fisheries management, the majority of exploited fish populations (98%) would recover to a healthy status, with a median time of recovery of about 10 years. Similarly, under the high emission scenario RCP8.5 and the SSP3 scenario (characterized by low economic development and a large increase in human population), maximizing the long term economic yield of the fishery was projected to increase the biomass of the skipjack tuna population (Dueri *et al.*, 2016). Recently, it was shown that reforming fisheries by adopting an optimal harvest policy that maximizes long-term economic benefits and that adapts its management strategy to climate-induced changes in fish biomass and spatial distribution could offset the detrimental impacts of climate change on future fish biomass and catch under most RCP greenhouse gas emission scenarios, except RCP8.5 (Gaines *et al.*,

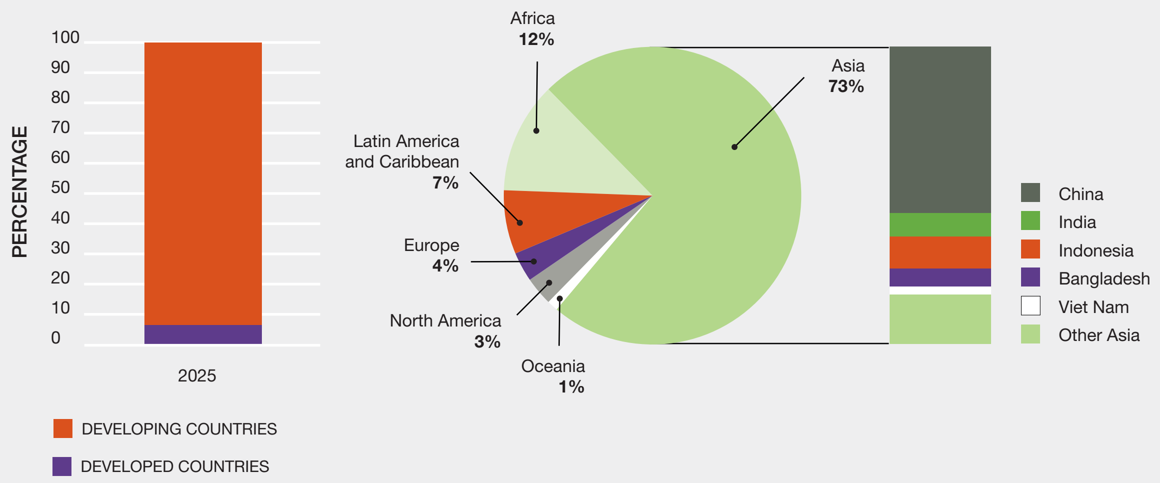


Figure 4 2 6 **Projections of additional fish consumed in 2025 (from fisheries and aquaculture) per world region.**

Developing countries are projected to eat 93 percent of the additional fish available for human consumption. Source: OECD and FAO (FAO, 2016).

2018). This important finding needs to be consolidated by further investigations in a context where fisheries maximum catch potential is projected to decrease by 2.8-5.3% and 7-12.1% by 2050 relative to 2000 under RCP2.6 and RCP8.5, respectively (Cheung *et al.*, 2018).

In addition to climate change (see 4.2.2.2.1), heavy fishing also impacts fish size, decreasing both the maximum size of species and the biomass of large-sized species because (i) high-value target species are generally larger, (ii) fishing gear is size-selective and often designed to remove larger fish, (iii) older and larger fish in a population become fewer as a result of accumulation of fishing mortality rate through time, and (iv) large species are more vulnerable because their life-history traits are generally linked to lower potential rates of increase (Shin *et al.*, 2005). Under heavy fishing, a SRES A1B climate change scenario was reported to magnify the reduction in fish size (Blanchard *et al.*, 2012). This shift towards smaller fish size and higher growth rates could ultimately increase the variability of fish biomass (Hsieh *et al.*, 2006).

Species targeted by fisheries are not the only species impacted by different fishing scenarios. Long-lived and vulnerable species such as marine mammals, turtles and birds suffer from direct impact of fish harvest though bycatch, and so their future is tightly linked to the long-term fishing strategies adopted. The interaction with climate change is complex to resolve but some studies have started addressing the potential synergistic effects. Some models based on species distribution projected that climate change will alter the future distribution of both fisheries and seabird populations, altering the rates of future bycatch and hence seabird mortality rates (Krüger *et al.*, 2018). For some species, spatial overlap with fisheries may decline, reducing rates of incidental mortality associated with human activity. However, for two highly threatened seabird species (grey-headed and wandering albatross), severe range reductions and increased overlap with fisheries are projected.

In addition to scenarios of fishing management, the future status of wild fish populations cannot be envisaged without considering alternative scenarios of aquaculture development which will play a major role in sustaining the supply of seafood products and the maintenance of per capita fish consumption (Delgado *et al.*, 2003; FAO *et al.*, 2018). But the development of aquaculture is partly dependent upon the exploitation of low trophic level fish species which supply fishmeal for farmed fish.

Aquaculture development could potentially reduce fishing pressure on wild fish populations, but not to an extent that could compensate for projections of increases in demand for seafood products and fishing technology, both of which result in increased fishing pressure (Quaas *et al.*, 2016). Taking into account projections in human population, climate change (IPCC A1B scenario), and technological development in aquaculture, a bio-economic model projected that if fishmeal prices increase, this would encourage fishers to maximize their short-term economic profits and exceed yearly quotas, leading to collapse of exploited fish populations (Merino *et al.*, 2012). Given the current increasing trends of fishmeal prices (Merino *et al.*, 2010), this implies that compliance to strict fisheries management and market stabilization measures need to be seriously considered to maintain exploited populations at sustainable levels. Likewise, another bio-economic model run under contrasted archetype scenarios suggested that relative to climate change impacts, fisheries regulation is the most important factor in determining the future of fish populations (Mullon *et al.*, 2016). However, the interplay between drivers of change cannot be ignored in fisheries management strategies (see example in **Box 4.2.3**). A multi-model ensemble approach allowed to show that the risk of negative synergistic effects between changes in primary production and in fishing effort was higher for small forage fish species (Fu *et al.*, 2018).

Box 4 2 3 Synergistic impacts of multiple drivers on tropical coral reefs.

Tropical coral reefs share a history of strong dependence on natural and human systems (Maire *et al.*, 2016) that must be accounted for in attempts to maintain long-term human development and well-being, and marine biodiversity (Cinner *et al.*, 2016). Indeed, coral reefs support the nutritional and economic needs of people in many developing countries. Their exceptional biodiversity translates directly into biomass production and thus food security (Duffy *et al.*, 2016). However, coral reefs face multiple and considerable challenges from ocean warming (see 4.2.2.2.2), ocean acidification, pollution, overexploitation and destructive fishing practices. More than 80% of the world's coral reefs are severely over-fished or have degraded habitats, thus imperiling the livelihood and sustenance of coastal human populations (McClanahan *et al.*, 2015). This negative spiral is likely to accelerate in the future due to the synergistic effects of climate change and direct human impacts. For example, nutrient loads from the land increases the vulnerability of corals to bleaching (Vega Thurber *et al.*, 2014). Plastic debris were estimated to increase coral susceptibility to diseases from 4% to 89% with structurally complex corals being eight times more likely to be affected by plastic (Lamb *et al.*, 2018) inducing a loss of fish productivity (Rogers *et al.*, 2014). Tipping points exist at which coral reef ecosystems can shift to being dominated by macroalgae (Holbrook *et al.*, 2016), with low resilience, reductions in biodiversity and degradation of the many ecosystem services they provide, such as reef-associated fisheries and tourism. However, there are opportunities for improving the status of coral reefs by the combined action of reducing both greenhouse gas emissions and overfishing of species which help the recovery of coral reefs by grazing their algal competitors (**Figure 4.2.7**; Kennedy *et al.*, 2013). Robust, integrated models that can account for combinations of multiple impacting drivers are still lacking, but these are needed to simulate the dynamics of coral reef social-ecological systems on a long-term basis and better anticipate their futures. This challenge is even more difficult given the multispecies nature of fisheries, the complexity of trophic interactions, and the time scales on which different processes determine the trajectories of coral reef social-ecological systems and the boundaries beyond which they collapse.

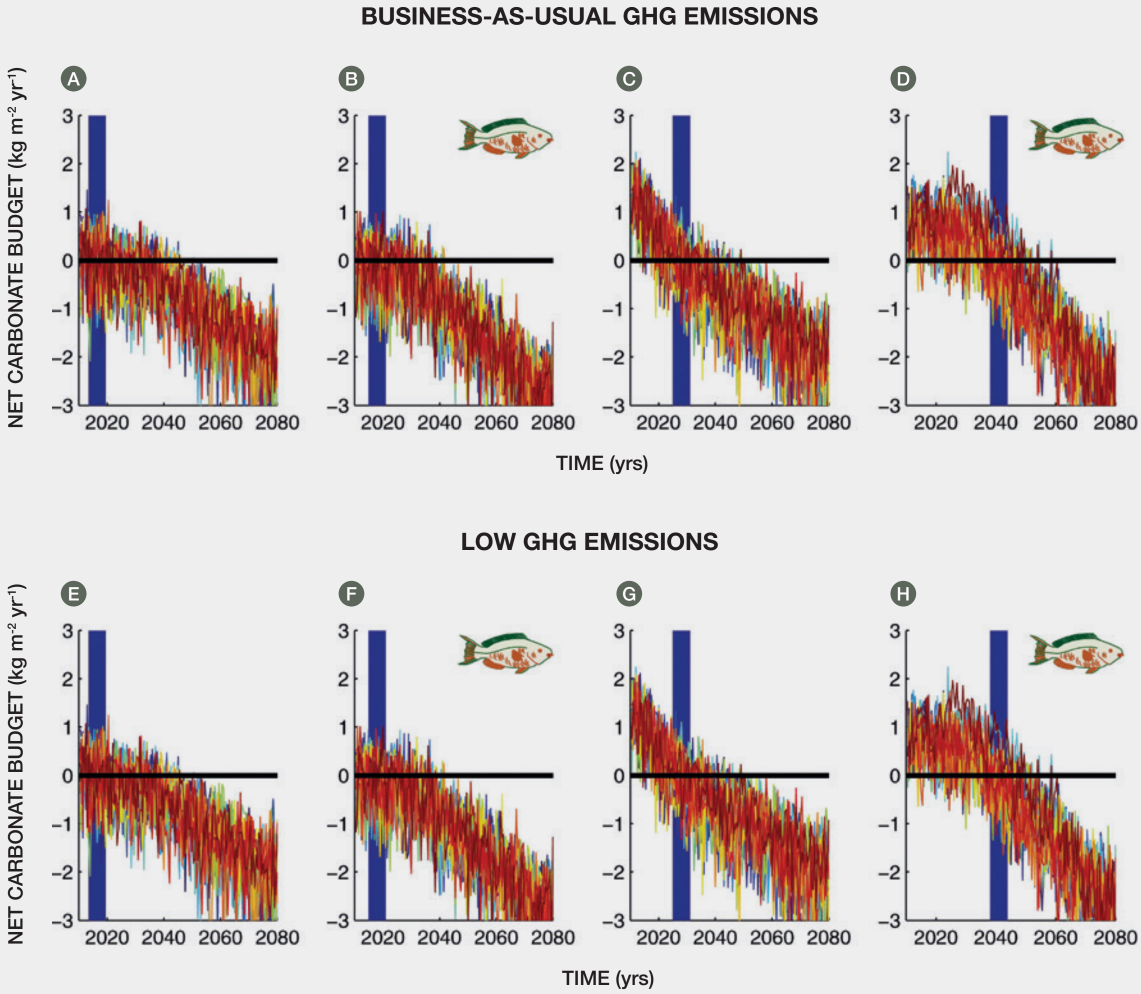


Figure 4 2 7 **Future carbonate budgets (proxy for net production of corals skeletons) of Caribbean coral reefs under climate change and acidification scenarios (top panel: high RCP8.5 greenhouse gas emission scenario, bottom panel: strong mitigation RCP2.6 emission scenario), without or with local conservation of grazing fish (parrot fish symbol in B, D, G, H).**

Initial conditions of reefs are either degraded with 10% coral cover (A, B, E, F) or healthier with 20% coral (C, D, G, H). Vertical blue bars indicate point at which the projected budget becomes negative (erosion of corals skeleton exceeds production). Source: Kennedy *et al.* (2013).

4.2.2.4 Future impacts of pollution on marine ecosystems

4.2.2.4.1 Persistent organic pollutants and plastics: another 'Silent Spring'?

Over the last century the human enterprise has fundamentally altered the planet by releasing large quantities of persistent organic pollutants (POPs) into the environment. These synthetic organic compounds have harmful and toxic properties and are not readily metabolized by bacteria or other life forms, thus prolonging their presence in the environment. Concerns about their effects on wildlife and people were first raised by Rachel Carson's book 'Silent Spring' (Carson, 1962), highlighting the devastating effects of organochlorine POPs on birds and aquatic animals in particular. As a result, many POPs were tightly regulated or banned under the Stockholm Convention (UNEP, 2001), and their production has ceased or decreased for most listed substances. Large historical burdens of these pollutants still circulate in the environment however (Harrad, 2009), and novel substances get synthesized at a rapid pace, with potentially harmful effects.

Synthetic organic polymers (plastics) form another class of pollutants that share certain properties with POPS in that they persist and accumulate in the environment, can be transported over long distances (reaching remote polar regions for example; Science for Environment Policy, 2017), and can have harmful effects on wildlife and people. In contrast to POPs, their production numbers are much higher overall and still increasing, thus global concerns about plastic pollution now match or exceed those for other POPs, particularly with respect to the marine environment which forms a sink for discarded plastic waste (Jambeck *et al.*, 2015; Worm *et al.*, 2017). Annual plastic production now exceeds 330 million metric tons (Mt) (PlasticsEurope, 2015), with a cumulative burden of 8300 Mt produced since 1950 (Geyer *et al.*, 2017), approximately 6300 Mt of which has been discarded (9% recycled, 12% incinerated, and 79% ended in landfills or the natural environment). If current production and waste management trends continue, roughly 12,000 Mt (million tons) of plastic waste will be in landfills or in the natural environment by 2050 **(Figure 4.2.8)**. If evenly spread around the globe, this would equal a burden of ~24 tons of plastic waste for each square kilometre of land and sea surface. This level of pollution in terms of volume and persistence has no previous analogue in human history.

Negative impacts on the planet and people are becoming more profound **(Figure 4.2.9)** as exposure to plastic pollutants intensifies. As an example, about 90% of seabirds examined today have plastic in their gut, with

CUMULATIVE PLASTIC WASTE GENERATION AND DISPOSAL

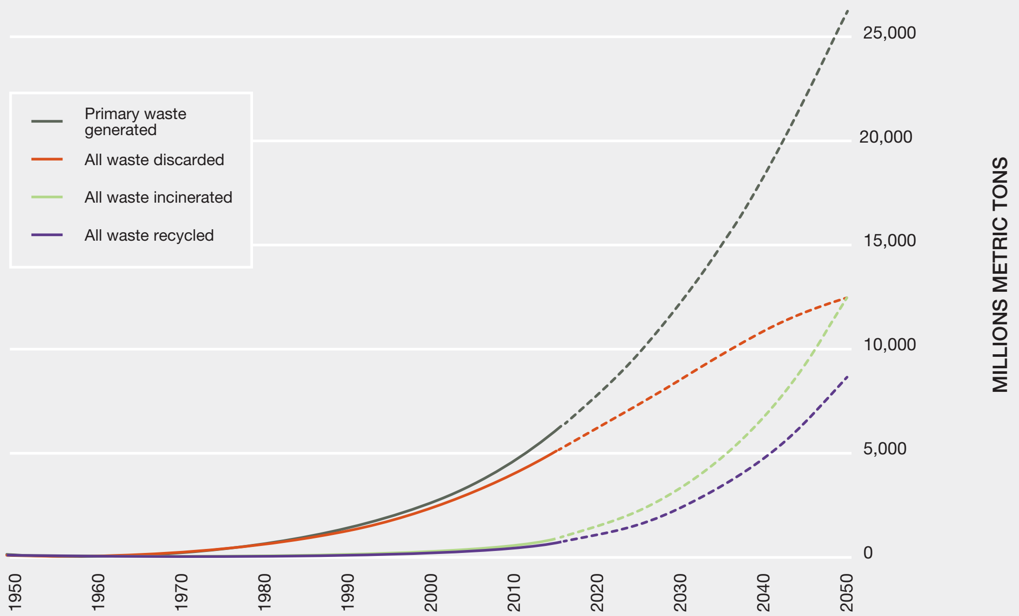


Figure 4 2 8 **Current global trends and likely future trajectories of total plastic waste generation and management.**

After data in Geyer *et al.* (2017).

100% expected to be exposed by 2050 (Wilcox *et al.*, 2015). Sea turtles are similarly affected (Schuyler *et al.*, 2015), as are at least 693 other marine species that have been recorded to be compromised by plastic pollution (CBD, 2016). Much of the plastic is released as or broken down into small microplastic (1 µm-1mm) or nanoplastic (<1µm) particles. While the harmful effects of microplastic debris are well understood, the long-term effects of the smallest fragments are only now emerging (Galloway & Lewis, 2016), including their tendency to interact with other pollutants (GESAMP, 2015), facilitate diseases (Lamb *et al.*, 2018), and transmit through the food chain **(Figure 4.2.9)**.

Clearly, another 'Silent spring' scenario seems plausible, if effects on numerous wildlife species continue to accelerate further. Because plastic persists and accumulates in the environment in similar ways POPs do, a zero-net-release policy that builds upon the successful Stockholm Convention (SC) on Persistent Organic Pollutants (POPs) may be a promising strategy to mitigate the risk posed by current and future levels of plastic pollution. Yet, in contrast to traditional POPs, which are largely emitted by industry, plastic pollution touches every person's life, and requires a broader societal effort including designers, producers, regulators, and consumers of plastic products to engage in comprehensive solutions (GESAMP, 2015; Worm *et al.*, 2017).

4.2.2.4.2 Nutrient loads and eutrophication

Numerous model projections show that coastal zones in many world regions are almost certain to see increases in nitrogen (N) and phosphorus (P) from increasing river loads in the coming decades (Sutton *et al.*, 2013; **Figure 4.2.10**). In contrast, silica (Si) river export is decreasing globally as a result of retention in the increasing number of reservoirs in the world's river systems and this trend will also continue in many parts of the world. The result of these simultaneous changes of N, P and Si will continue to alter nutrient stoichiometry, affecting not only total algal growth but also biodiversity in coastal waters, including the propensity for harmful algal blooms (HABs). The enhanced primary production in coastal surface waters can cause eutrophication, with subsequent sinking of excess degradable organic matter to bottom waters where aerobic microbial decomposition reduces oxygen concentration. The decline in oxygen concentrations due to nutrient loads in coastal waters will likely be exacerbated with climate change, due to decreased oxygen solubility in warmer waters and decreased oxygen transport to deeper waters because of stronger stratification of the water column (Breitburg *et al.*, 2018). The expansion of areas of low oxygen will impact marine biodiversity at all levels from individuals' physiology and behavior, to populations' demography and range shifts with consequences for

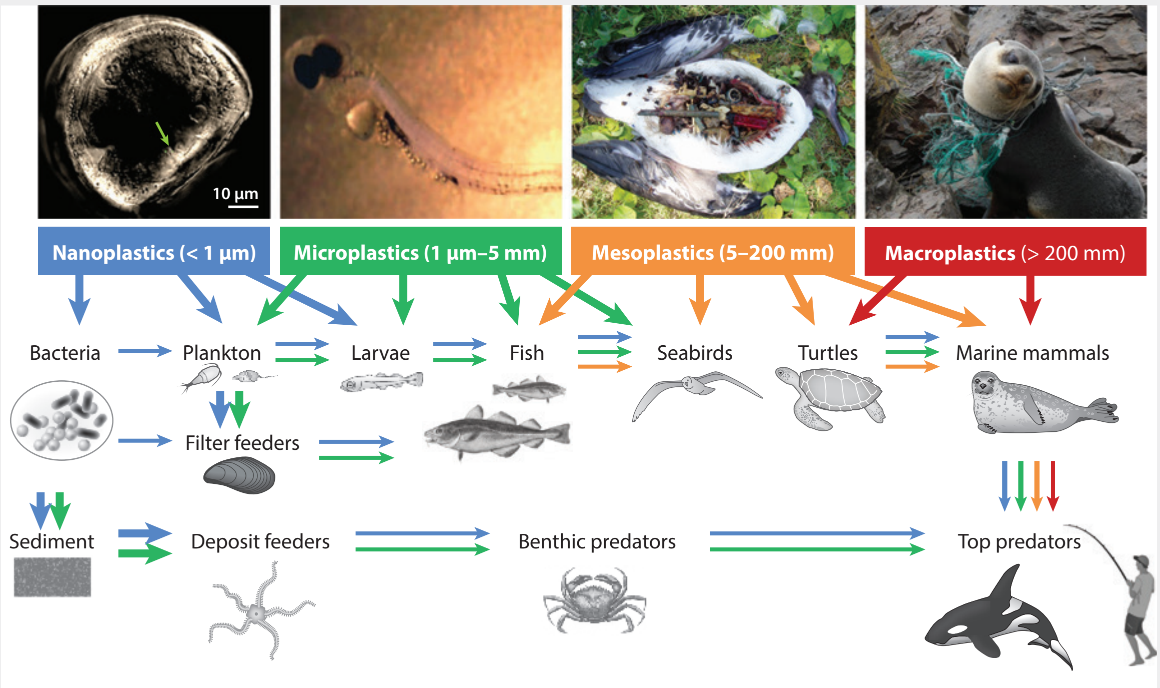


Figure 4 2 9 **Possible pathways by which plastic pollutants of different size classes enter the food chain and propagate to higher trophic levels, including humans.**

After Worm *et al.* (2017).

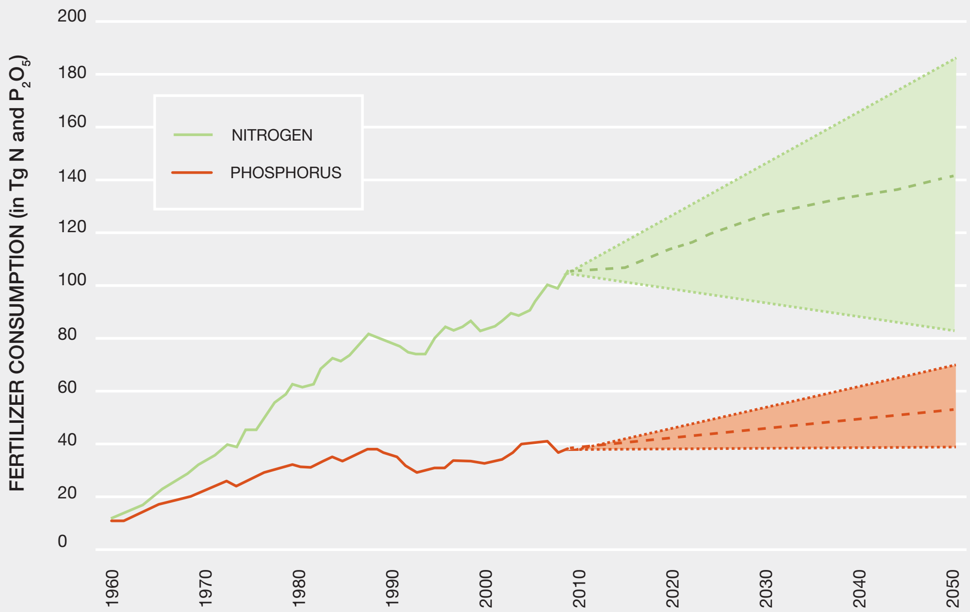


Figure 4 2 10 **Trends in global mineral fertilizer consumption for nitrogen and phosphorus and projected possible futures.**

Source: Sutton *et al.*, 2013.

species assemblages and food-webs (Levin *et al.*, 2009; Pörtner *et al.*, 2014).

Storylines developed by the IPCC and the Millennium Ecosystem Assessment and translated into changes of the main anthropogenic drivers, i.e. economic development, demography and land use (Alcamo *et al.*, 2007), have been applied to project conditions to 2050. Although each storyline has different assumptions, they show major increases in N and P river export especially in South and Eastern Asia, in South America and Africa where fertilizer use will likely increase to support the population, and where urbanization and lagging treatment of wastewater and sewage connection will lead to increasing nutrient discharge to surface water (e.g., Glibert *et al.*, 2018). In contrast, stabilized or decreasing trends in nutrient loads are projected in Europe, North America and Australia owing to the development of improved wastewater treatment systems, and improved nutrient management reducing NH_3 volatilization, leaching and run-off. In these regions, improvements in hypoxia and frequency or magnitude of HABs may be realized.

However, the trajectory of nutrient loads is additive with other global changes, such as temperature rise, which will alter stratification of the water column, availability of nutrients and their forms and ratios, and pCO2, among other factors (e.g., Boyd & Doney, 2003). Recent models supported evidence for increased eutrophication together with climate changes, and therefore the propensity for the worsening of HABs and/or hypoxia by the end of the century (Sinha *et al.*, 2017). Multiple combined changes such as increases in nutrient pollution, in global temperature and in reservoir capacity resulting in increased retentiveness of rivers, require proactive management to stabilize or reduce the impacts of eutrophication, including hypoxia and the frequency of HABs.

4.2.2.5 Future impacts of coastal development on marine ecosystems

Direct human-related drivers of change such as urbanization, coastal development, and land-use change will bring challenges to coastal ecosystems in addition to climate change. Coastal populations are increasing disproportionately relative to the global population increase. Many of emerging cities are on the coast and their growth will add to the 75% of the world's mega-cities which are already coastally located (World Economic Forum's Ocean Programme, 2017). Over 2.6 billion people live on or near the coast, many in developing countries where dependence on coastal resources may be high and demand for multiple benefits such as food, coastal protection and income, will continue to grow as human populations expand (Bell *et al.*, 2009; Sale *et al.*, 2014). Some 1.36 billion live on tropical coasts, and this is projected to grow to 1.95 billion by 2050, with associated pollution and eutrophication of coastal waters and degradation of coastal ecosystems (Sale *et al.*, 2014). Urbanization and coastal development can restrict the capacity of coastal ecosystems to adapt to rising sea levels e.g. through the "coastal squeeze" (Wong *et al.*, 2014). Along urbanized coastlines, the resilience of wetlands to SLR will depend on the availability of accommodation space (Schuerch *et al.*, 2018) and sediment supply (Lovelock *et al.*, 2015) which are reduced by anthropogenic infrastructure barriers (e.g., flood protection structures, roads, settlements). Future expansion of coastal development will also bring risks to iconic and threatened species. For example, the expansion of artificial lighting at night from coastal development interrupts the sea-finding behaviour of sea turtle hatchlings and ultimately survivorship (Gaston & Bennie, 2014; Kamrowski *et al.*, 2014).

Future projections show a multiplicity of human stressors acting simultaneously with direct climate-induced changes on social-ecological systems. Stressors from population growth and coastal development such as nutrient run-off, urbanization, and land-use change are expected to increase and combine with climate stressors such as sea level rise and warming to exacerbate risks for rocky and sandy shores, and seagrasses **(Box 4.2.4)**. Models show that mangroves are particularly threatened by projected coastal development, with the main direct drivers including the expansion of aquaculture (prevalent in both Asia and Latin America) and agriculture (mostly rice cultivation and pasture), extraction of timber and related forest products (e.g., for charcoal and domestic construction), and infrastructure development and alterations of freshwater flows (e.g., for due to settlements, transportation networks or dams) (Roy Chowdhury *et al.*, 2017). Under projected changes, coastal adaptation options will involve increasingly difficult trade-offs in future among multiple development and biodiversity objectives (Mills *et al.*, 2015).

4.2.3 Freshwater ecosystems

4.2.3.1 Freshwater biodiversity and current threats

Freshwater ecosystems provide fundamental services to humans such as food, water, nutrient retention, recreation, and climate regulation. Globally, freshwaters (i.e. rivers, lakes, wetlands) represent less than 0.02% of Earth's water volume and cover only about 0.8% of Earth's surface (Dawson & Dawson, 2012). However, an estimated 129,000 species live in freshwater ecosystems, representing ~8% of Earth's described species (Balian *et al.*, 2008; **Figure 4.2.11**). The relative contribution of freshwater ecosystems to global biodiversity is thus extremely high (Tedesco *et al.*, 2017; Wiens, 2016). Climate, productivity and area size drive freshwater diversity patterns globally despite profound functional differences between taxa (Moomaw *et al.*, 2018; Tisseuil *et al.*, 2013).

Box 4 2 4 Synergistic impacts of multiple pressures on seagrass meadows.

Direct human-related drivers of change such as urbanization, coastal development, and land-use change will bring challenges to coastal ecosystems. For seagrasses, key threats include sediment and nutrient run-off from upstream land-use change, physical disturbance, algal blooms, and invasive species, as well as climate warming and disease (Orth *et al.*, 2006; Waycott *et al.*, 2009). Requirements for clear water and low nutrient concentrations make seagrasses vulnerable to eutrophication, as nutrient and sediment loading reduce light availability and favor faster-growing algae (Burkholder *et al.*, 2007; Duffy *et al.*, 2013). The protected embayments in which seagrasses grow best are also prime real estate for coastal and harbor development. As a result seagrasses are declining worldwide, and roughly 30% of global seagrass cover has been lost since the first estimates were made in the late 19th century, with loss rates increasing in recent decades (Waycott *et al.*, 2009). Ten of the 72 known seagrass species on earth are at elevated risk of extinction and three species are classified as Endangered (Short *et al.*, 2011).

Perennial organisms such as seagrasses are vulnerable to human disturbance and, under repeated impacts, often yield dominance to faster growing, opportunistic species such as fleshy and filamentous algae. In the Baltic Sea, for example, dominance by eelgrass and rockweed has yielded over recent decades to accumulations of ephemeral algae (Bonsdorff *et al.*, 1997). Long-term field monitoring suggests that exploitation of piscivores such as cod in offshore waters has released the smaller inshore fishes—mesopredators—from top-down control, and their consumption of grazing invertebrates indirectly led to algal blooms and decline of perennial seagrasses (Eriksson *et al.*, 2011). Coastal vegetation, including seagrasses, protects coastal human communities against storm damage, and the continuing decline of these natural barriers will likely be aggravated by SLR. Coastal habitat loss exacerbates damage from storms and flooding in coastal communities (Gedan *et al.*, 2011). Mapping the risk of such hazards along the coastline of the USA shows that, under several projected climate scenarios, the number of people, especially the poor and elderly, and the total value of residential property exposed to hazards could be reduced by half by preserving existing coastal habitats (Arkema *et al.*, 2013).

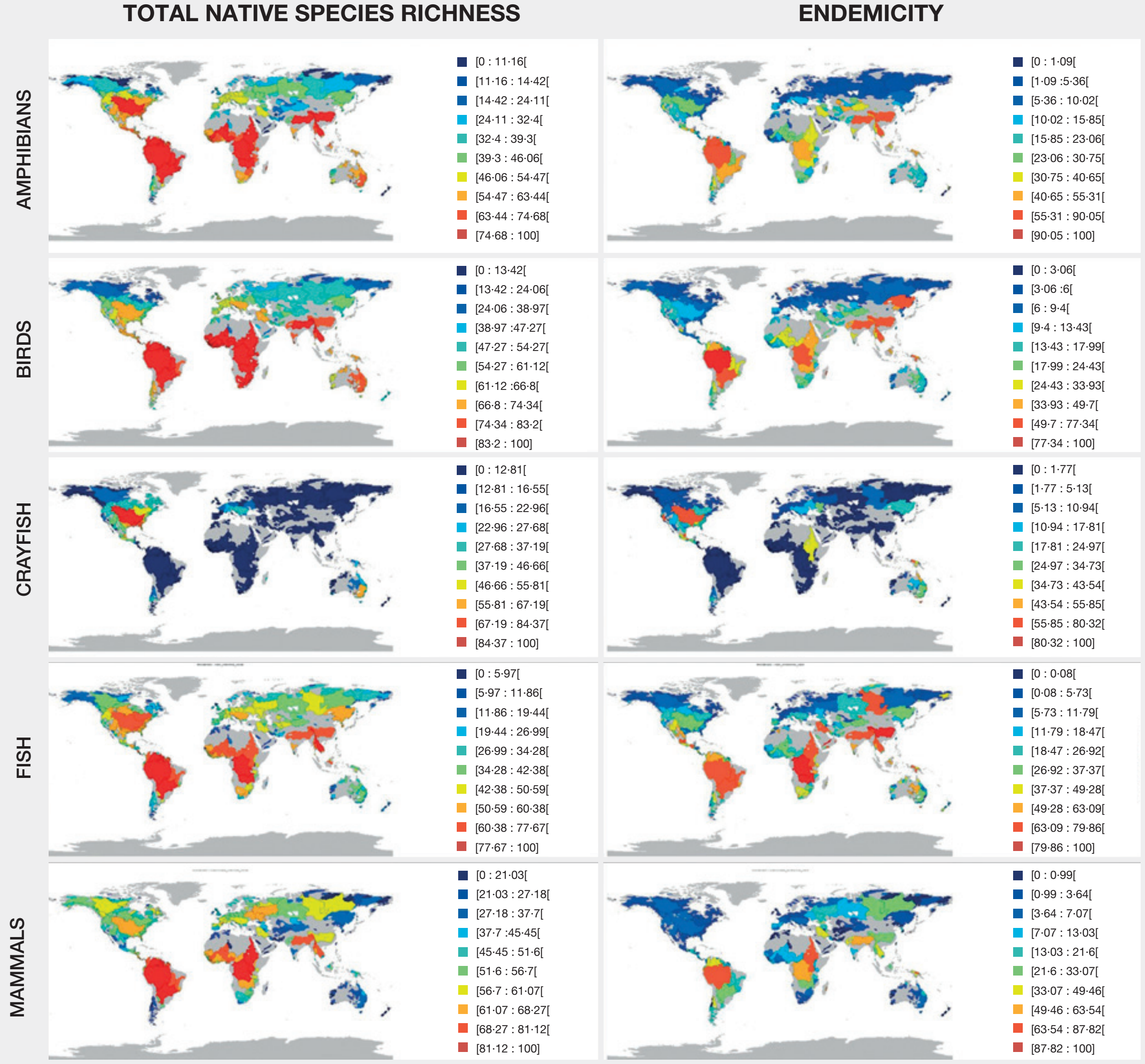


Figure 4 2 11 **Global diversity maps (species richness and endemicity) for freshwater fishes, aquatic amphibians, aquatic mammals, crayfish and aquatic birds.**

For comparison purpose, the diversity descriptor values of each taxon are rescaled between 0 and 100. Study based on the global distributions of 13, 413 freshwater species among five taxonomic groups (i.e. 462 crayfish, 3263 amphibians, 8870 fish, 699 birds and 119 mammals) and conducted on 819 river drainage basins covering nearly 80% of Earth's surface. After Tisseuil *et al.* (2013).

Current major threats to freshwater biodiversity include climate change, habitat modification and pollution from land-use, habitat fragmentation and flow regime homogenization by dams, non-native species, increased eutrophication resulting from nutrient and organic discharges, water abstraction, and overexploitation (Young *et al.*, 2016). Those threats currently affect freshwater biodiversity and functioning to varying degrees (Carpenter *et al.*, 2011; Vörösmarty *et al.*, 2010), and their additive and potentially synergistic effects may further threaten future freshwater biodiversity and resources (Collen *et al.*, 2014; Knouft & Ficklin, 2017).

4.2.3.2 Future climate change impacts on freshwater biodiversity and ecosystem functioning

The lowest greenhouse gas emissions scenario is the only scenario not expected to threaten much of global freshwater biodiversity in 2050 through direct effects of climate change. Under all other scenarios, freshwater biodiversity is expected to decrease proportionally to the degree of warming and precipitation alteration. All water body types on all continents are likely to be affected. Warmer waters will alter community structure, food webs, body sizes, and species ranges — especially in regions where semi-arid and Mediterranean climates currently occur as well as high-mountain ecosystems. In addition to reduced biodiversity and ecosystem functioning, warmer and less water will lead to species extinctions because of habitat shrinkage.

Scenarios of climate change impacts on global freshwater ecosystem biodiversity and functioning were reviewed by Settele *et al.* (2014). Climate change alters freshwater ecosystems and their biodiversity by changing (1) temperatures, (2) water availability and (3) flow regimes through changes in precipitation (Döll & Zhang, 2010; Knouft & Ficklin, 2017) and/or temperature (Blöschl *et al.*, 2017). Increased water temperatures often lead to progressive shifts in the structure and composition of assemblages because of changes in species metabolic rates, body size, migration timing, recruitment, range size and interactions (Daufresne *et al.*, 2009; Myers *et al.*, 2017; Parmesan, 2006; Pecl *et al.*, 2017; Rosenzweig *et al.*, 2008; Scheffers *et al.*, 2016). There is already evidence of regional and continental shifts in freshwater organism distributions following their thermal niches (Comte *et al.*, 2013), local extirpations through range contractions at the warm edges of species' ranges (Wiens, 2016), and body size reductions (Daufresne *et al.*, 2009). Warmer water temperatures also enhance microorganism metabolism and processing of organic matter (unless dissolved oxygen is limiting), causing eutrophication when nutrient levels are high (Carpenter *et al.*, 2011; Mantyka-Pringle *et al.*, 2014) as well as increased omnivory. Warming also induces phenological mismatches between consumers and resources in highly seasonal environments, potentially destabilizing food-web structure (Woodward *et al.*, 2010a).

The strongest temperature increases are projected for eastern North America (0.7 to 1.2 °C under RCP2.6 and RCP8.5, respectively, by 2050), Europe (0.8 to 1.2 °C), Asia (0.6 to 1.2°C), southern Africa (>2.0°C under RCP8.5) (van Vliet *et al.*, 2016b) and Australia (CSIRO & Bureau of Meteorology, 2015). Moderate water temperature increases (<1.0°C) by 2050 are predicted for South America and Central Africa (Van Vliet *et al.*, 2013; van Vliet *et al.*, 2016b). Changes in water temperature are projected to lead to local or regional population extinctions for cold-water species because of range shrinking especially under the RCP 4.5, 6.0 and 8.5 scenarios (Comte & Olden, 2017). Most lowland-tropical freshwater species are expected to tolerate warmer conditions where water is sufficient (Comte & Olden, 2017).

Decreased water availability and altered flow regimes reduce habitat size and heterogeneity. This increases population extinction rates because the probability of species extinctions increases with reduced habitat size (Tedesco *et al.*, 2013). Climate change can also alter flow regime seasonality and variability (e.g., Blöschl *et al.*, 2017; Döll & Zhang, 2010) and increase flow intermittency (Pyne & Poff, 2017). This would lead to decreased food chain lengths through loss of large-bodied top predators (Sabo *et al.*, 2010), altered nutrient loading and water quality (Woodward *et al.*, 2010b), and/or pushing taxa into novel trajectories from which they may not recover (Bogan & Lytle, 2011). However, whatever the RCP scenario, climate change impacts on the timing of seasonal streamflow are found to be generally small globally (Eisner *et al.*, 2017). Yet, relative to water availability and according to the wet-wetter/dry-dryer mechanism (Gudmundsson *et al.*, 2017; Held & Soden, 2006; Wang *et al.*, 2017), more severe water stress in current drylands is expected in the future. Although under RCP2.6 the distributions of water availability may change little by the end of the 21st century, RCP4.5, 6 and 8.5 scenarios are expected to induce substantial shrinking of water drainage where semi-arid and Mediterranean climates currently occur. Reduced water availability in those regions, including shifts from permanence to intermittency, will generate population extirpations of all types of freshwater organisms (Jaeger *et al.*, 2014), leading to global net biodiversity losses because endemism is usually high in those regions. For example, projected fish extinction rates from drainage shrinking under the high emission SRES A2 scenario in river basins worldwide show that among the 10% most-altered basins, water availability loss is likely to increase background extinction rates by 18.2 times in 2090 (Tedesco *et al.*, 2013; **Figure 4.2.12**). Also, in glacier-fed high-mountain ecosystems, significant changes to snow and glacier melt regimes, including glacier disappearance, have already been observed (Leadley *et al.*, 2014) and are expected to continue (Kraaijenbrink *et al.*, 2017). This leads to reduced water availability and declines in biodiversity through local population extirpations and species extinctions in regions of high endemicity in all water body types. Besides biodiversity losses, losses of glacial ice in closed drainages and flows in semi-arid regions (Vörösmarty *et al.*, 2010) will substantially decrease water for agriculture, power and public water supply, thereby increasing economic vulnerability in the affected regions (e.g., Moon, 2017).

Wetlands, including peatland and permafrost regions, sequester carbon in their soils. But when confronted to warming, drying and conversions to agriculture, wetlands are expected to release CO_2, CH_4, and N_2O. Global warming alone is projected to contribute 1.6 x 10^8 kilotons of carbon from melting permafrost to the atmosphere and CH_4 emissions from freshwater wetlands are projected to nearly double by 2100 (Moomaw *et al.*, 2018). Such changes are very likely to impact biodiversity negatively due to habitat loss and reduced water quality, which increase the risk of extinctions and extirpations of wetland endemic and dependent species (Segan *et al.*, 2016).

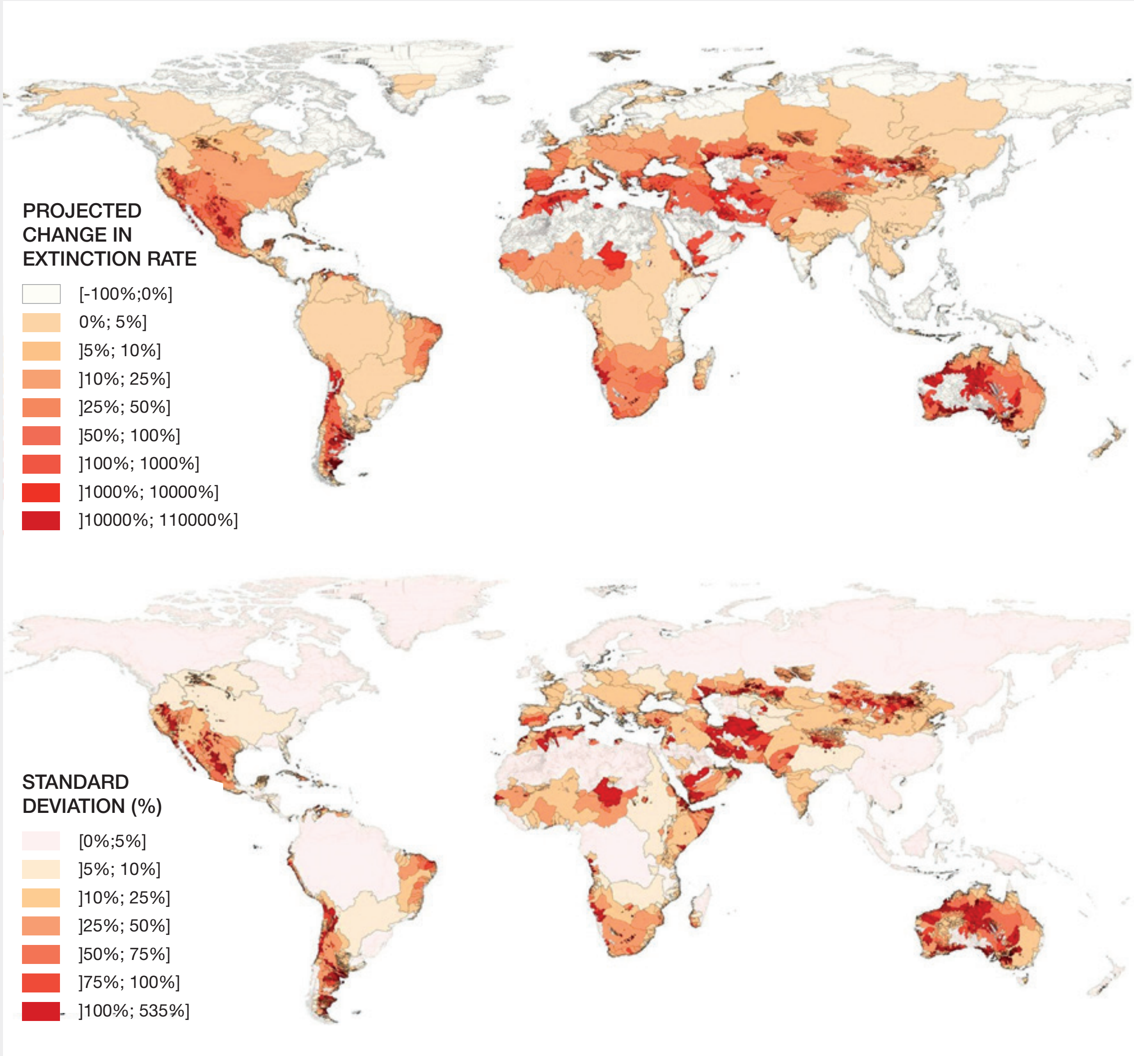


Figure 4 2 12 **Global patterns of proportional increase or decrease in freshwater fish extinction rates between current climatic conditions and future (2090) under the most 'pessimistic' IPCC SRES scenario (A2).**

Negative values of projected change in extinction rate depict drainage basins where extinction rates may decrease, while positive values depict drainage basins where extinction rates may increase. 91 949 river drainage basins covering ~99% of the terrestrial surface. After Tedesco *et al.* (2013).

4.2.3.3 Future land-use change impacts on freshwater biodiversity and ecosystem functioning

Land use will likely increase the risk of eutrophication, leading to local population extinctions, changes in community structure and consequent modification of the food-web, ecosystem temporal instability, and establishment and spread of pathogens and toxic cyanobacteria blooms globally. Land use will become especially problematic in the emerging tropical economies because of increased human population density and weak pollution controls. Increasing pollution and eutrophication will degrade water quality, impair biological resource availability, reduce nutrition in developing countries, and reduce recreational opportunities and tourism income. Globally increased toxic cyanobacteria blooms and pathogens will increase health risks for people and livestock. These risks will most affect closed water bodies and estuaries, but rivers will also be threatened. The additional impact of future increasing use of pesticides in agriculture is hard to quantify due to a lack of scenario studies.

Land use, especially croplands, mining and urbanization, will affect freshwater ecosystems and associated biodiversity through two main pathways. First, further increased water and groundwater withdrawals are expected to decrease habitat (water) availability for freshwater organisms leading to increased population extinction rates in rivers and lakes or direct extinctions from wetland conversions (Gardner *et al.*, 2015; Tilman *et al.*, 2001). The problem is exacerbated in semi-arid regions where water withdrawals lead to some rivers and lakes drying routinely, with ensuing species extinctions (Foley *et al.*, 2005). Second, water quality is usually degraded by land use, and this trend is likely to continue. Intensive agriculture increases sediment, nutrient and pesticide loads to ground and surface waters (Lotze *et al.*, 2006; Vasconcelos *et al.*, 2017). The continuing, rapid urbanization also will substantially degrade water quality in many regions mostly through organic or phosphorous loadings, especially where wastewater treatment is absent. Mining leads to increased loadings of toxic metals, salts and acids (Daniel *et al.*, 2015; Hughes *et al.*, 2016). Such pollutants induce direct local mortality, impaired individual development and health, and altered community structure (Muturi *et al.*, 2017), particularly for predators through bioaccumulation (Carpenter *et al.*, 2011). Since nutrient loadings progressively lead to increased eutrophication, oxygen depletion, animal mortality, extirpation of submerged macrophytes and the production of algal blooms (including toxic varieties of cyanobacteria) (Foley *et al.*, 2005; Paerl & Paul, 2012), efforts to wastewater treatment related to all anthropogenic activities will need to increase. Pollutants affect in particular the biodiversity and functioning of closed systems and estuaries (Lotze *et al.*, 2006). For example, urban point sources have been the leading cause of hypoxia across European lakes since 1850 (Jenny *et al.*, 2016). Furthermore, continued deforestation, a key component of land-use change, will further disrupt organic matter processing and food webs, exacerbating the establishment and spread of pests and pathogens, especially in tropical regions (Morris *et al.*, 2016).

Future scenarios of changes in cropland area, pasture, forest and other natural land diverge widely depending on the underlying socio-economic assumptions (see sections 4.1 and 4.2.4) (Alexander *et al.*, 2017c; Popp *et al.*, 2017; van Vuuren *et al.*, 2011). For the RCP4.5 scenario, a decrease of cropland and pasture was projected in one study (van Vuuren *et al.*, 2011), which is expected to minimize future freshwater biodiversity disturbances. However, the global scenarios mask regional dissimilarities. For example, projections of future primary vegetation show major decreases in western and middle Asia (RCPs 2.6, 6.0 and 8.5), Australia (only RCP2.6) and North America (only RCP 8.5) (Settele *et al.*, 2014).

Water pollution has been considerably reduced in Australia, North America and Western Europe (Vörösmarty *et al.*, 2010), except for pharmaceuticals, biocides and plastics because of ineffective treatment (Ebele *et al.*, 2017). Reduced water pollution will benefit freshwater biodiversity. However, Sinha *et al.* (2017) projected increased eutrophication induced by increased precipitation from climate change in some regions, and Oliver *et al.* (2017) projected no decrease in nitrogen and phosphorus concentrations for most USA lakes despite attempts to reduce diffuse pollution. If there is little technology transfer to developing countries, then water pollution may increasingly threaten freshwater ecosystems, particularly in tropical regions because of increased human density notably in Asia and Africa, that are expected to account for over half of global population growth between 2015 and 2050 (UNDESA, 2015). Under RCP2.6, if much agricultural, mineral and bioenergy production relocates from high-income to low-income regions, pollution, freshwater biodiversity and aquatic ecosystem functioning will further worsen in those regions.

4.2.3.4 Future impacts of habitat fragmentation on freshwater biodiversity and ecosystem functioning

Hydropower is expected to increase worldwide whatever the RCP scenario unless other renewable energy sources are installed. Regions where significant losses in streamflow and decreased capacity production are projected, or where human population is expected to continue to increase (such as in many countries of Africa), should be most affected. Fragmentation of rivers by dams increases species extinction risks by blocking spawning/rearing migrations and/or reducing population sizes and gene flow.

Hydropower infrastructures alter rivers, floodplain lakes, wetlands and estuaries. Dams transform river basins by creating artificial lakes locally, fragmenting river networks, and greatly distorting natural patterns of sediment transport and seasonal variations in water temperatures and flows (Latrubesse *et al.*, 2017). Altered flow seasonality in rivers has led to less diverse fish assemblages, decreased inland fisheries production, less stable bird populations and lower riparian forest production (Jardine *et al.*, 2015; Kingsford *et al.*, 2017; Sabo *et al.*, 2017). Sediment retention by dams leads to delta recession (Luo *et al.*, 2017), decreased coastal fisheries catches, and degraded tropical mangrove forests that are major carbon sinks (Atwood *et al.*, 2017).

Dams also prevent upstream-downstream movement of freshwater animals, facilitate settlement of non-native species, cause local species extirpations and replacements and increase risk of water-borne diseases in reservoirs and highly altered environments by modifying productivity (Fenwick, 2006; LeRoy Poff & Schmidt, 2016). Dams have also caused a significant displacement of IPLCs around the world and projected expansion of dams, as shown in **Figure 4.2.13**, suggest significant overlap with areas held and/or managed by IPLCs (Garnett *et al.*, 2018). The fragmentation of river corridors also reduces population sizes and gene flows of aquatic species, increasing species extinction risks (Cohen *et al.*, 2016; Dias *et al.*, 2017). Dams are mainly concentrated in highly industrialized regions, but future hydropower development will be concentrated in developing countries and emerging economies (Grill *et al.*, 2015; Zarfl *et al.*, 2015). Hydropower is expected to expand worldwide whatever the RCP scenario **(Figure 4.2.13)**. Most hydropower plants are currently situated in regions where considerable declines in streamflow are projected, resulting in mean reductions in usable hydropower capacity (Turner *et al.*, 2017; van Vliet *et al.*, 2016b). Those regions may increase dam building to compensate for the losses unless other energy options are implemented (Zarfl *et al.*, 2015). Also, growing population density is expected to also increase demands for hydropower globally, especially in tropical regions (Winemiller *et al.*, 2016) where freshwater biodiversity is concentrated (Tisseuil *et al.*, 2013; UNDP, 2016).

4.2.3.5 Future impacts of non-native species on freshwater biodiversity and functioning

Future threats to freshwater ecosystems from non-native species will be greater in emerging economies because of accelerated economic growth, whatever the scenario. Non-native species often compete with and prey upon native species, generating occasional local population extirpations (Carpenter *et al.*, 2011), altering ecosystem structure and function (e.g., Blanchet *et al.*, 2010; Toussaint *et al.*, 2018), spreading infectious diseases (Gagne *et al.*, 2018) and sometimes degrading ecosystem services and economies (Leung *et al.*, 2002). They are a key contributor to biotic homogenization of aquatic ecosystems globally (Rahel, 2007; Villeger *et al.*, 2011). Anthropogenic disturbances coupled with introductions of non-native fish (particularly piscivores) are associated with native species extirpations and range reductions, especially in lakes and reservoirs (Whittier & Kincaid, 1999), as well as rivers (Hughes & Herlihy, 2012). In addition, reduced ecosystem services, particularly water quality, are likely to deteriorate as a result. Although policies have been implemented to prevent new introductions globally (McGeoch *et al.*, 2010 see chapter 6), the increase in the numbers of non-native species shows no sign of saturation over time. Also, many non-native species are predicted to spread worldwide in the next decades, mainly because of climate change, accelerated economic exchanges among countries, construction of new transportation corridors and increased aquaculture (Seebens *et al.*, 2017). These projections seem to occur in all RCP scenarios but especially so under the RCP 4.5, 6.0 and 8.5.

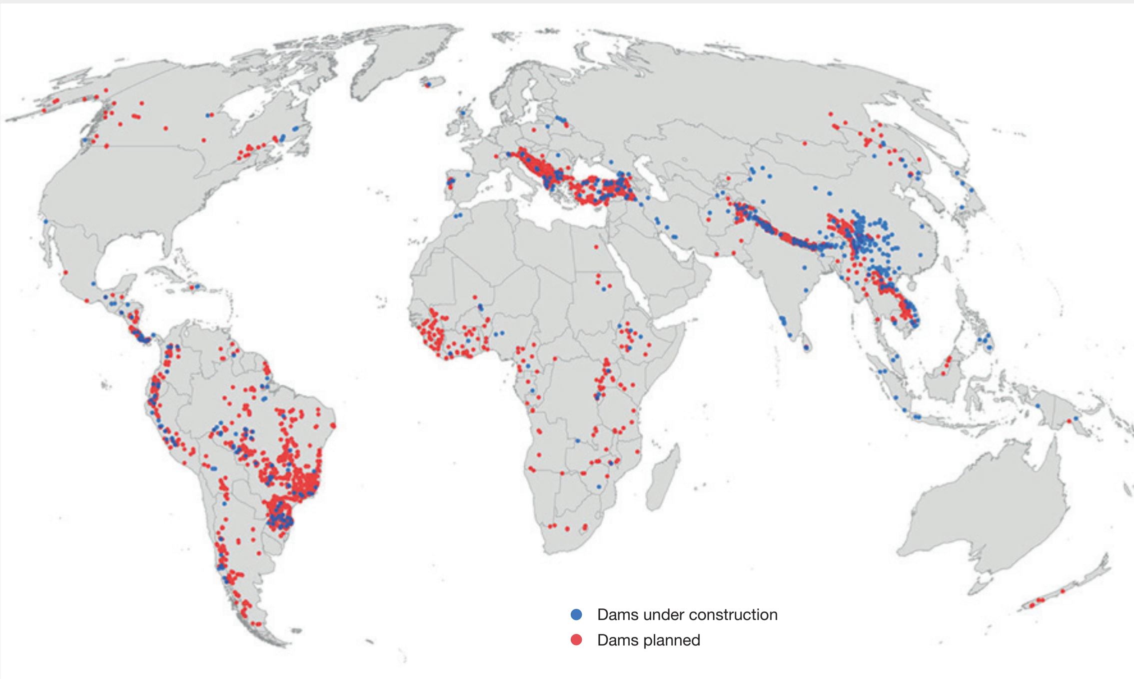


Figure 4 2 13 **Distribution of future hydropower dams, either under construction (blue dots 17%) or planned (red dots 83%).**

Source: Zarfl *et al.* (2015).

4.2.3.6 Future impacts of harvest on freshwater biodiversity and functioning

Irrespective of the exact type of scenario, given that human population density is continuously growing, increased harvesting is expected. Tropical ecosystems are of greatest concern. Intensive harvesting will deplete large-bodied fishes with consequent shifts toward harvests of smaller species and younger individuals with potential top-down effects on food web dynamics.

Current estimates of inland fisheries harvest are greatly underestimated (Deines *et al.*, 2017), but inland fisheries provide food for billions and livelihood for millions of people worldwide (FAO, 2016), and will continue to do so especially in developing countries. Low-income food-deficient countries account for ~80% of the total reported harvest from inland capture fisheries (Lynch *et al.*, 2016). Most global harvesting is concentrated in 16 countries, which have annual inland catches >200,000 tons and together represent 80% of the world total (FAO, 2016). Asian countries represent 63% of global total catches and African nations >13%. Harvests in African and Asian water bodies are already declining, probably because of environmental degradation and overexploitation (FAO, 2016). Given expected human population increases in Africa and Asia, increased harvesting is expected in both continents, whatever the RCP scenario. Because harvesting decreases population densities and large-bodied species, increased fishing pressure will lead to local extirpations of these species and will alter community structure and food web dynamics (Allan *et al.*, 2005; McIntyre *et al.*, 2016). These effects will be magnified by interactions with the other anthropogenic stressors listed above, including climate change. Because contributions of inland fisheries to economic security are inversely proportional to development level, rural economies in developing countries will be most affected.

4.2.3.7 Future impacts on peatlands

Peatlands are important flor global carbon cycling projections because they account for about one-third of the total carbon stored in soil organic matter (Page *et al.*, 2011) and also because many peatlands are an important source of methane (CH_4) (Kirschke *et al.*, 2013; Saunois *et al.*, 2016). Peatlands are threatened by future agriculture, forestry, peat extraction and dam construction activities (Minayeva *et al.*, 2017), which already over recent decades have begun transforming peatlands from greenhouse gas sinks to sources (Frolking *et al.*, 2011; Strack, 2008). For example, 15% of global peatlands have been drained worldwide and these drained peatlands are currently responsible for ~5% of all global anthropogenic CO_2 emissions (Strack, 2008).

While some regions appear to be improving peatland protection, others are increasing peatland destruction (Giam *et al.*, 2012; Hooijer *et al.*, 2010; Jauhiainen *et al.*, 2012; Koh *et al.*, 2011). Climate change is projected to possibly amplify shifts of peatlands from GHG sinks to sources, especially in regions where water tables are highly sensitive to local precipitation and where permafrost is melting (Dargie *et al.*, 2017; Turetsky *et al.*, 2015). A model intercomparison experiment showed that both peatland area and CH_4 emissions were less sensitive to potential future changes in precipitation than to increases in either atmospheric CO_2 or temperature (Melton *et al.*, 2013), but models disagree widely in both the magnitude and sign of potential climate effects on peatlands.

Where demands for water, food and energy put increasing pressure on the land resources, it is likely that peatland area will continue to decline (http://luh.umd.edu). Consequently, CO_2 emissions from peat decomposition and oxidation will expectedly persist well beyond the 21st century. Tropical regions are projected to be most affected under scenarios where much agriculture and bioenergy production relocate from high-income to low-income regions (Lawrence *et al.*, 2016). Considering the over proportional warming projected for subarctic and arctic ecosystems and the large amount of carbon stored in peatlands on permafrost soils, large climate warming feedbacks have been projected (Koven *et al.*, 2011; Page & Baird, 2016).

While plant and animal taxonomic diversity in peatland ecosystems is apparently low, highly specialized species predominate, with 5–25% of peatland plant species being endemic (Minayeva *et al.*, 2017). Many animal species occupy peatlands only at certain life stages or during particular seasons (but see Giam *et al.*, 2012 for some narrowly adapted fish species). Because of their unique flora, projected lost peatland area has implications for global biodiversity. In all scenarios, and without peatland conservation practices, climate change and other anthropogenic drivers are expected to disrupt peatland biodiversity to varying degrees, ranging from decreased population sizes to altered species composition and regional or global extinctions (Fraixedas *et al.*, 2017; Giam *et al.*, 2012; Hedwall *et al.*, 2017). For example, in Southeast Asia, if current rates of peatland conversions to agriculture continue through 2050, several fish species will become globally extinct (Giam *et al.*, 2012).

4.2.4 Terrestrial ecosystems

4.2.4.1 Future climate change and atmospheric CO_2 impacts on habitats, biodiversity, and ecosystem state and functioning

4.2.4.1.1 Climate change impacts on vegetation cover

Global vegetation and Earth system models all project substantial climate change driven shifts of natural vegetation cover over the next century (Davies-Barnard *et al.*, 2015; Gonzalez *et al.*, 2010; Ostberg *et al.*, 2013; Pereira *et al.*, 2010; Reu *et al.*, 2014; Sitch *et al.*, 2008; Wårlind *et al.*, 2014; Warszawski *et al.*, 2013). Area losses of natural vegetation are estimated to be 2-47% of terrestrial ecosystems for even relatively small temperature increases (<2°C above pre-industrial; Warren *et al.* (2011), and references therein). Other analyses confirm the risk of changes in vegetation cover (e.g., forest to non-forest or vice versa) for relatively small global temperature increases, especially in tundra, tropical forest and savanna regions but with changes within a given biome likely to occur in all regions (Gonzalez *et al.*, 2010; IPCC, 2018, Chapter 3.4.3; Ostberg *et al.*, 2013; Scholze *et al.*, 2006; Warszawski *et al.*, 2013). Biome shifts and associated impacts on ecosystem functioning increase notably in higher-warming scenarios (Ostberg *et al.*, 2013; Scholze *et al.*, 2006; Warren *et al.*, 2011; Warszawski *et al.*, 2013). Enhanced tree mortality from wildfires and increased drought and heatwaves can amplify vegetation responses to climate in models (Allen *et al.*, 2010; Lasslop *et al.*, 2016; Tietjen *et al.*, 2017).

4.2.4.1.2 Climate change impacts on species diversity

In principle, climatic changes could be favourable to some species in cases when a new climate can provide more resources for species growth, reproduction and distribution (Bellard *et al.*, 2012). However, even by the middle of the 21st century, or for relatively minor temperature changes, indices for animal and plant species richness have been projected to decline, and indices of species losses, enhanced (Alkemade *et al.*, 2013, 2009; Bellard *et al.*, 2012; Gonzalez *et al.*, 2010; IPCC, 2018, Chapter 3.4.3; Pereira *et al.*, 2010; Settele *et al.*, 2014; Warren *et al.*, 2011). Climate change has also been identified as a major driver of terrestrial species loss across all IPBES regional assessments (Bustamante *et al.*, 2018; Elbakidze *et al.*, 2018; Nyingi *et al.*, 2018; Wu *et al.*, 2018). A recent meta-analysis of studies reported that a global mean temperature increase of 2°C would threaten one in 20 species (for 5.2% of species, the distributional range falls below a minimum threshold), increasing to one in 12 and one in 6 species for 3°C and 4.3°C, respectively (Urban, 2015). Model projections across a range of scenarios show regionally highly variable extinction risks for terrestrial species on average between ca. 5-7% (Europe, Northern America) to ca. 25% (South America), ca. 9% in the tropics, and ca. 5% in temperate, polar and boreal environments, by 2100 (Maclean & Wilson, 2011; Urban, 2015). The projected extinction risk increases strongly with degree of global warming (Urban, 2015). Large uncertainties exist: for instance, extinction risks estimates when based on extrapolation of past observed trends have been found to be higher than the estimates based on model projections (Maclean & Wilson, 2011).

Climate change will impact biodiversity hotspots. Two contrasting future scenarios at the end of the 21st century have been estimated to negatively influence 25% of endemic species on average per hotspot, with largest effects in low latitudes, island locations and in Mediterranean type climates (Bellard *et al.*, 2014). Nearly all of the 143 investigated terrestrial regions in the Global 200 list of ecoregions that have been identified to support maintaining a broad diversity of Earth's ecosystems, will likely experience by the end of the 21st century moderate-to-pronounced climate change impacts, across a range of climate change scenarios (Li *et al.*, 2013).

Since the magnitude but also the velocity of climate change are chief determinants of whether (and which) terrestrial animal or plant species will be able to follow shifting habitats (Foden *et al.*, 2013; Gonzalez *et al.*, 2010; Keenan, 2015; Loarie *et al.*, 2009; Pecl *et al.*, 2017; Pereira *et al.*, 2010), the combination of abiotic and biotic characteristics that have not been observed in the past might be increasingly common in the future (Murcia *et al.*, 2014; Ordonez *et al.*, 2016; Radeloff *et al.*, 2015). Projected future changes in species ranges, species extinctions and community diversity therefore may be under– or overestimated by models that do not explicitly account for species interactions such that loss (or gain) of one species would trigger loss (or gain) for others (Bellard *et al.*, 2012; Schleuning *et al.*, 2016). As a consequence, new approaches to conservation are warranted that are designed to adapt to rapid changes in species composition and ensuing conservation challenges.

4.2.4.1.3 The combined impact of atmospheric CO_2 concentration and climate change on projected vegetation cover

Increasing atmospheric CO_2, the chief driver of climate change, also enhances relative competitiveness of plants of the C3 photosynthetic pathway by fostering carboxylation reactions in the leaf and allowing plants to operate at reduced stomatal conductance (Higgins & Scheiter, 2012; Pugh *et al.*, 2016b; Walker *et al.*, 2015). Whether or not enhanced photosynthesis or enhanced water use efficiency translates also into enhanced plant growth is not yet unequivocally established (Higgins & Scheiter, 2012; Pugh *et al.*, 2016b; Walker *et al.*, 2015). Globally, increased forest cover over the 21st century has been projected across a range of scenarios (Davies-Barnard *et al.*, 2015; Reu *et al.*, 2014; Sitch *et al.*, 2008; Wårlind *et al.*, 2014). Typically, forest cover increases in northern latitudes (Davies-Barnard *et al.*, 2015; Reu *et al.*, 2014; Sitch *et al.*, 2008; Wårlind *et al.*, 2014). A shift from grass- to increasingly woody-dominated vegetation (see Nyingi *et al.*, 2018) is simulated in semi-arid regions (Knorr *et al.*, 2016; Lehmann *et al.*, 2014; Lehsten *et al.*, 2009; Moncrieff *et al.*, 2014, 2016; Scheiter *et al.*, 2015). Impacts of enhanced CO_2 on canopy structure and combustible biomass alter fire regimes, with complex ecosystem feedbacks (Harris *et al.*, 2016; Jiang *et al.*, 2017; Kim *et al.*, 2017; Knorr *et al.*, 2016; Loudermilk *et al.*, 2013; Turco *et al.*, 2014; Wu *et al.*, 2015). Large-scale forest "die-back" emerges only in relatively few simulation experiments that examined future climate change and CO_2 impacts in tropical forest regions, especially the Amazon (Aragão *et al.*, 2014; Duran & Gianoli, 2013; Gumpenberger *et al.*, 2010; Malhi *et al.*, 2009, 2008; Nobre *et al.*, 2016; Poulter *et al.*, 2010; Rammig *et al.*, 2010; Schnitzer & Bongers, 2011). These model outcomes are supported by analyses that attributed the observed greening trends in many regions and (C3) shrub encroachment in C4-dominated grasslands chiefly to CO_2 fertilisation effects (Donohue *et al.*, 2013; Schimel *et al.*, 2015; Stevens *et al.*, 2016; Zhu *et al.*, 2016). Increases in woody vegetation in grass-dominated regions are expected to negatively impact grassland-related biodiversity (Barbosa da Silva *et al.*, 2016) but intermediate levels of woody cover might in some cases be beneficial for ecosystem functioning such as carbon storage, reduction of soil erosion and overall plant and animal species diversity (Barbosa da Silva *et al.*, 2016; Eldridge & Soliveres, 2014; Soliveres *et al.*, 2014).

4.2.4.1.4 Projected changes in ecosystem state and function

The uptake of CO_2 in land ecosystems is large, with 20-25% of anthropogenic emissions being removed from the atmosphere each year (Le Quéré *et al.*, 2018; see also Chapter 2.2, section 2.2.5.2.2). The future persistence of this land carbon "sink" is one of the largest uncertainties in climate research. It is important to address because of the potentially large warming feedback associated with a loss of the land sink (Arneth *et al.*, 2010; Ciais *et al.*, 2013). The direction (but not the magnitude) of the change in global terrestrial carbon uptake and pool sizes in response to climate change alone vs. increased CO_2 concentration alone is modelled relatively robustly (Ciais *et al.*, 2013; Hajima *et al.*, 2014; Nishina *et al.*, 2015; Sitch *et al.*, 2008; Walker *et al.*, 2015; Zaehle, 2013). However, when effects of climate change and CO_2 concentration are considered jointly, the rate and even the sign of change in simulated trajectories of future ecosystem C pools and related fluxes are highly inconsistent between ecosystem carbon cycle models (Ciais *et al.*, 2013; Eglin *et al.*, 2010; Friend *et al.*, 2014; Nishina *et al.*, 2015; Piao *et al.*, 2013; Sitch *et al.*, 2008). The latest IPCC report places low confidence on how stocks and fluxes will evolve over the coming decades (Ciais *et al.*, 2013).

Evapotranspiration (ET) from ecosystems is greatly altered by changes in leaf area, functional vegetation type, precipitation and atmospheric dryness, and the response of stomatal conductance to CO_2. Whether or not global or regional run-off (which affects availability of water for irrigation but also floods) will increase in the future due to enhanced water cycles in a warmer climate, or possibly reduced ET in a higher CO_2 world is unresolved. Similar to projections of ecosystem productivity and carbon balance, uncertainty arises from both variability in climate change projections and from process descriptions in impact models (Döll & Schmied, 2012; Piao *et al.*, 2007; Zhang *et al.*, 2014).

Overall, climate change, and change in atmospheric CO_2 levels will strongly impact productivity and other important ecosystem processes, vegetation cover, and habitat structure over the next decades, with the relative importance of these drivers differing between biomes/regions (see **Figure 4.2.2** and Table A4.2.1).

4.2.4.2 Future land-use and land-cover change impacts on habitats, biodiversity, and ecosystem state and functioning

Nearly 40% of the land surface today is used as croplands or pastures, and humans have transformed the vegetation structure and species composition in an area far greater still (Ellis, 2013; Ellis *et al.*, 2012; see also Chapters 2.1 and 2.2). Local within-sample richness, rarefaction-based species richness, and total abundance have all been shown to be generally lower in areas under different types and intensity of land use, compared with natural vegetation (Alkemade *et al.*, 2009; Newbold *et al.*, 2015; Wilting *et al.*, 2017; Chapter 2.2.). In some cases, species richness, at least for plants, can also increase under land use, such as documented in local management systems for agriculture and agroforestry, forests, meadows and grasslands found around the world (Ellis *et al.*, 2012; Gerstner *et al.*, 2014; see also Chapter 2.2). Both, changes in land cover and land use, are known to impact biodiversity and ecosystem functioning globally (Foley *et al.*, 2011; Kleijn *et al.*, 2009; Pywell *et al.*, 2012). But across large scales, studies typically assess impacts of land cover changes, rather than intensification of management at a given area of land which limits our ability to understand the combined effect of land-use and land-cover change (de Chazal & Rounsevell, 2009; Titeux *et al.*, 2017).

Humid or mesic savannas and woodlands seem particularly vulnerable to future conversion of natural vegetation into cropland or pasture, because of their climate suitability for agriculture. Land-use changes have been very pronounced in recent decade; for example, in the Cerrado or Chaco regions of South America, but also in African savannas (Aleman *et al.*, 2017, 2016; Cavender-Bares *et al.*, 2018; Nyingi *et al.*, 2018; Searchinger *et al.*, 2015; see also Chapter 2.1).

Land conversion pressure is large both in scenarios that explore high population growth and lack of consideration for sustainable development (e.g., lack of conservation efforts, little consumption change), as well as in strong mitigation scenarios that require land for bioenergy or afforestation (Popp *et al.*, 2017; see also section 4.2.4.3). Due to large land area requirements, maintaining or enhancing biodiversity and ecosystem functionality (such as productivity and changes in carbon pools or changes in water cycling) would be challenging under such socio-economic projections (Krause *et al.*, 2017, 2018; Popp *et al.*, 2017; Ryan *et al.*, 2016; Searchinger *et al.*, 2015).

Projections of future biodiversity at the global level have until recently been biased towards climate change related questions (Titeux *et al.*, 2016, 2017). Anthropogenic land-cover changes have been relatively well studied at the regional and local levels, particularly but not only in tropical forests regions, but are only slowly beginning to be considered in global scenario projections. Declining forest cover and/or reduced average local species richness, for 2050 and until the end of the 21st century have been found under "economic optimism" scenarios, such as the SSP5/RCP8.5 which projects large greenhouse gas emissions and climate change effects along with substantial expansion of cropland or pastures (Davies-Barnard *et al.*, 2015; Newbold *et al.*, 2015), or under scenarios that assume the absence of a REDD scheme (Strassburg *et al.*, 2012). Interactions of future climate change with land-cover change were shown to enhance risk of biodiversity loss by up to 43% for birds and 24% for mammals, compared to land-cover change impacts only (Mantyka-Pringle *et al.*, 2015). By 2050 in a business-as-usual scenario, climate and land-cover change were shown to lead to a decline in mean terrestrial carnivore and ungulate population abundance by 18-35%, and to an increase in extinction risk for 8-23% of species (Visconti *et al.*, 2016). Negative impacts are also projected to arise from land-cover and land-use changes on a range of threatened carnivores in an OECD Environment Outlook scenario (Di Minin *et al.*, 2016). Taken together these studies demonstrate that across a range of scenarios, expansion of managed land is projected to pose additional pressure on biodiversity. The relative impacts of climate change versus land-use change on biodiversity, however, are context-specific and vary between scenarios and regions, and depend on the biodiversity indicator or facet of biodiversity under scrutiny, as emphasised by the four regional IPBES assessments (e.g., Bustamante *et al.*, 2018; Elbakidze *et al.*, 2018; Nyingi *et al.*, 2018; Wu *et al.*, 2018) and also by very recent results emerging from the BES-SIM study (Kim *et al.*, 2018; **Box 4.2.5**; see also section 4.1).

Future anthropogenic land-cover change will also impact protected areas and the associated protected species range (see section 4.6). Even when implemented efficiently, the percentage area protected would have to increase to capture a similar rage of terrestrial vertebrate species range in simulations that include projections of land cover change over the next two decades, compared with land-cover change remaining at present-day levels (Montesino Pouzols *et al.*, 2014).

Box 4 2 5 Biodiversity and nature's contributions to people in the Shared Socio-economic Pathway scenarios: a model inter-comparison.

Background. In 2016, IPBES created a task force to support the scientific community in developing scenarios and models to provide IPBES and other stakeholders with greatly improved capacity to assess the future impacts of global environmental change on biodiversity and nature's contributions to people (IPBES, 2016b; Rosa *et al.*, 2017). This work focuses on two complementary tasks. The first task is to work closely with the climate change community to analyze and extend the 'Shared Socio-economic Pathways (SSP)' scenarios and associated climate change projections that have been developed in support of the IPCC (Rosa *et al.*, 2017). The results presented below are the first outcomes from this task referred to as BES-SIM (Kim *et al.*, 2018). The second task is to develop a set of multi-scale, participatory based scenarios that explicitly account for nature conservation objectives. This task is ongoing, and the outcomes will only become available for future assessments.

The results presented below are from the first-ever comparison of multiple models of terrestrial biodiversity, ecosystem functioning and ecosystem services at the global scale using a common set of inputs for climate and land-use change drivers (Kim *et al.*, 2018), addressing shortcomings in previous comparative attempts that have been hampered by the lack of a common methodology (Bellard *et al.*, 2012; Pereira *et al.*, 2010; Settele *et al.*, 2014; Urban, 2015; Warren *et al.*, 2011). Using a total of 14 participating models, ten different indicators of biodiversity were simulated and six models contributed simulations of ecosystem function and ecosystem services (Kim *et al.*, 2018).

All models of biodiversity, ecosystem function and ecosystem services used harmonized land-use inputs from three SSP scenarios in combination with three scenarios of greenhouse gas emissions (RCP) and corresponding projected climate change (Kim *et al.*, 2018):

- SSP1 x RCP2.6 – is a 'global sustainability' scenario archetype (SSP1) combined with low GHG emissions (RCP2.6),
- SSP3 x RCP6.0 – is a 'regional competition' scenario archetype (SSP3) combined with high GHG emissions (RCP6.0), and
- SSP5 x RCP8.5 – is an 'economic optimism' scenario (SSP5) combined with very high GHG emissions (RCP8.5).

Climate and land-use change projections from these three sets of scenarios (see section 4.1.4, and Appendix A4.2.3) were evaluated for their consequences for biodiversity, ecosystem functions and ecosystem services. In addition, some of the participating models evaluated the impacts of climate change and land-use change individually, as well as in combination. Outputs from ecosystem functioning and ecosystem services models have been grouped into categories of nature's contributions to people as defined in Diaz *et al.* (2018).

Biodiversity and regulating nature's contributions to people are projected to decline while material contributions to people increase by 2050. The global average of projected impacts on biodiversity and on nature's contributions to people are shown in **Figure 4.2.14**. The combined impacts of climate and land-use change on biodiversity include large declines in local species richness, increases in regional to global scale species extinction and declines in biodiversity intactness. Several important regulating ecosystem services, such as coastal protection, soil erosion protection and crop pollination, are projected to decline in the 'regional competition (SSP3xRCP6.0)' and 'economic optimism (SSP5xRCP8.5)' scenarios.

In contrast, food, feed, timber and bioenergy production services are projected to substantially increase in these scenarios. This pattern of trade-offs between declining biodiversity and regulating contributions on one hand vs. increasing material contributions on the other hand are coherent with recent patterns (Carpenter *et al.*, 2009; see Chapters 2 and 3) and with a wide range of studies of biodiversity and ecosystem services evaluated in this chapter (sections 4.3 and 4.5).

Not all of the metrics follow this general pattern. One important example is ecosystem carbon storage at the global scale, which is an indicator of the capacity of ecosystems to contribute to climate change mitigation. Global scale ecosystem carbon storage is projected to be stable or increase in nearly all scenarios and in all ecosystem models by 2050 (see Table A4.2.2 in Appendix A4.2.3). This occurs in part because rising atmospheric CO_2 concentrations and rising temperatures (up to certain point) stimulate modeled plant productivity and ecosystem carbon storage, as well as the result of land-use change in the scenarios.

There are large regional differences in the patterns of biodiversity loss and changes in nature's contributions to people with the largest projected impacts in the global south **(Figure 4.2.15)**. The projected effects of land use and climate change on three metrics of biodiversity, material nature's contributions to people and regulating nature's contributions to people for the IPBES subregions are shown in Figure A4.2.1 in Appendix A4.2.3. The general patterns at the global level – i.e., declines in biodiversity and regulation contributions vs. increases in material contributions – are evident in nearly all subregions. Biodiversity in South America, Africa and Asia (with the exception of northeast Asia) is much more heavily impacted than in other regions, especially in the regional competition and economic optimism scenarios. Ecosystem carbon storage shows particularly contrasted regional responses, with very large declines projected for Africa. These regional differences occur in part because scenarios foresee the largest land-use conversions to crops or bioenergy in these regions (see section 4.1.5 and Appendix A4.1.2). Other regions such as North America and Europe are foreseen to have low conversion to crops and continued trends of afforestation which minimizes declines in biodiversity, or even increases in some regional biodiversity metrics. Regional differences in climate change impacts also play a major, and sometimes dominant role in regional contrasts.

The magnitude of impacts and the differences between regions are much greater in scenarios of regional competition and economic optimism than in a scenario of global sustainability. Biodiversity loss at the global scale is much lower in the global sustainability scenario (SSP1xRCP2.6) than in the regional competition and economic optimism scenarios and even improves for the biodiversity intactness metric. Several regulating services, such as crop pollination and soil protection, increase at the global scale in the global sustainability scenario instead of declining as in the other two scenarios, and in general, the impacts of land use and climate change are much greater in the regional competition and economic optimism scenarios **(Figure 4.2.14)**. In contrast, the global sustainability scenario results in substantially lower projected food, feed and timber production, but it is important to note that this arises primarily from lower demand rather than insufficient supply of food and timber to people. The regional competition and economic optimism scenarios also are projected to generate much greater regional contrasts in biodiversity and nature's contributions than the global sustainability scenario **(Figure 4.2.15)**. But caution should be exercised when generalizing from these three scenarios because there is substantial variation in land use and other drivers within each of the main Shared Socio-economic Pathway classes (Popp *et al.*, 2017).

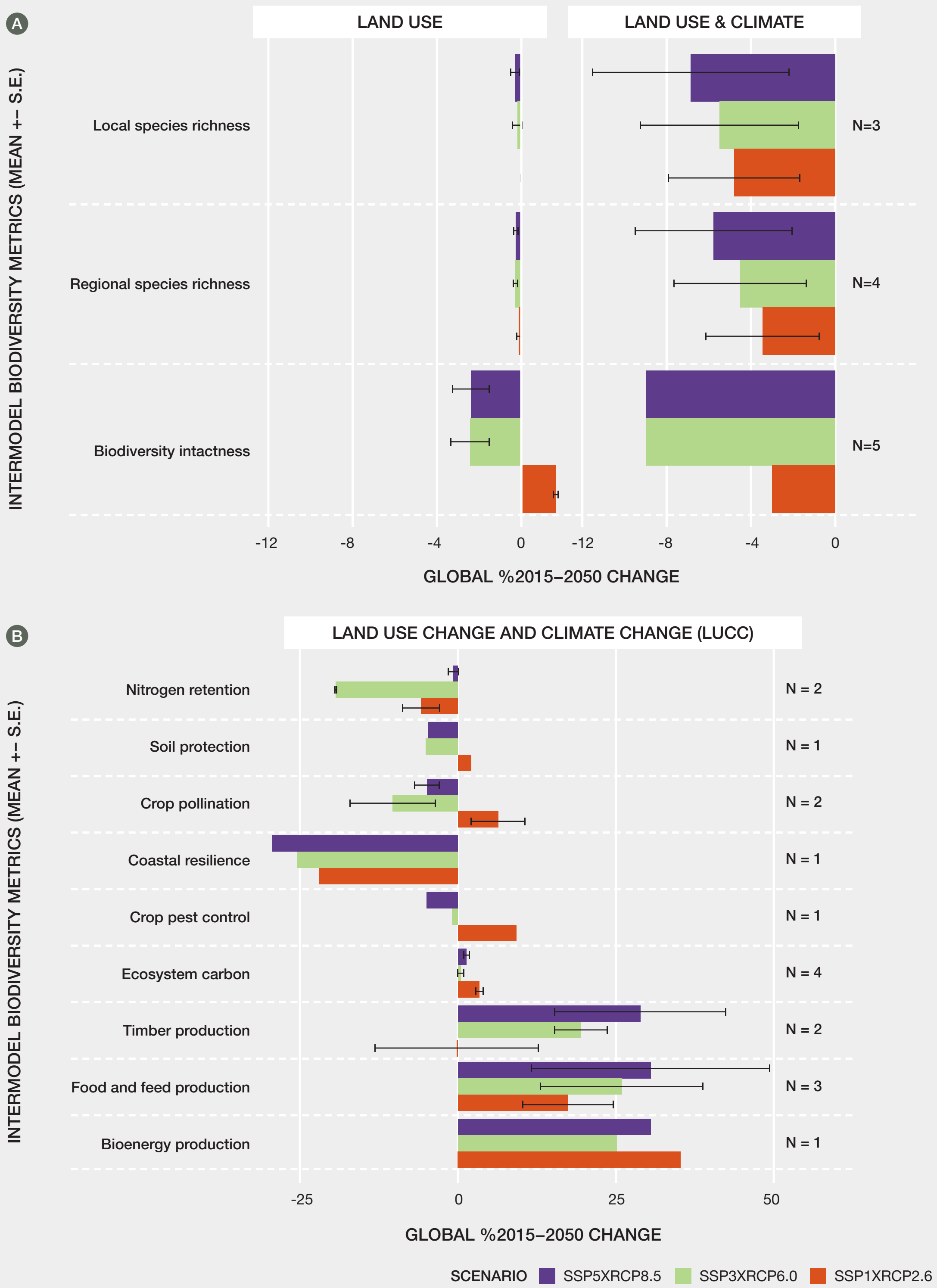


Figure 4 2 14 **Global means of projected percent changes in biodiversity A and nature's contributions to people B between 2015 and 2050.**

Biodiversity metrics include changes in local species richness (= number of species in a small area), regional species richness (number of species at regional or global scales, the opposite of which is regional or global extinction), and biodiversity intactness (i.e., abundance of plant and animal communities in disturbed compared to undisturbed natural ecosystems). Values are averages across models, which number is indicated by N. Standard errors across models are indicated by whiskers when more than one model projection was available. The three SSPxRCP scenarios are defined in the box text.

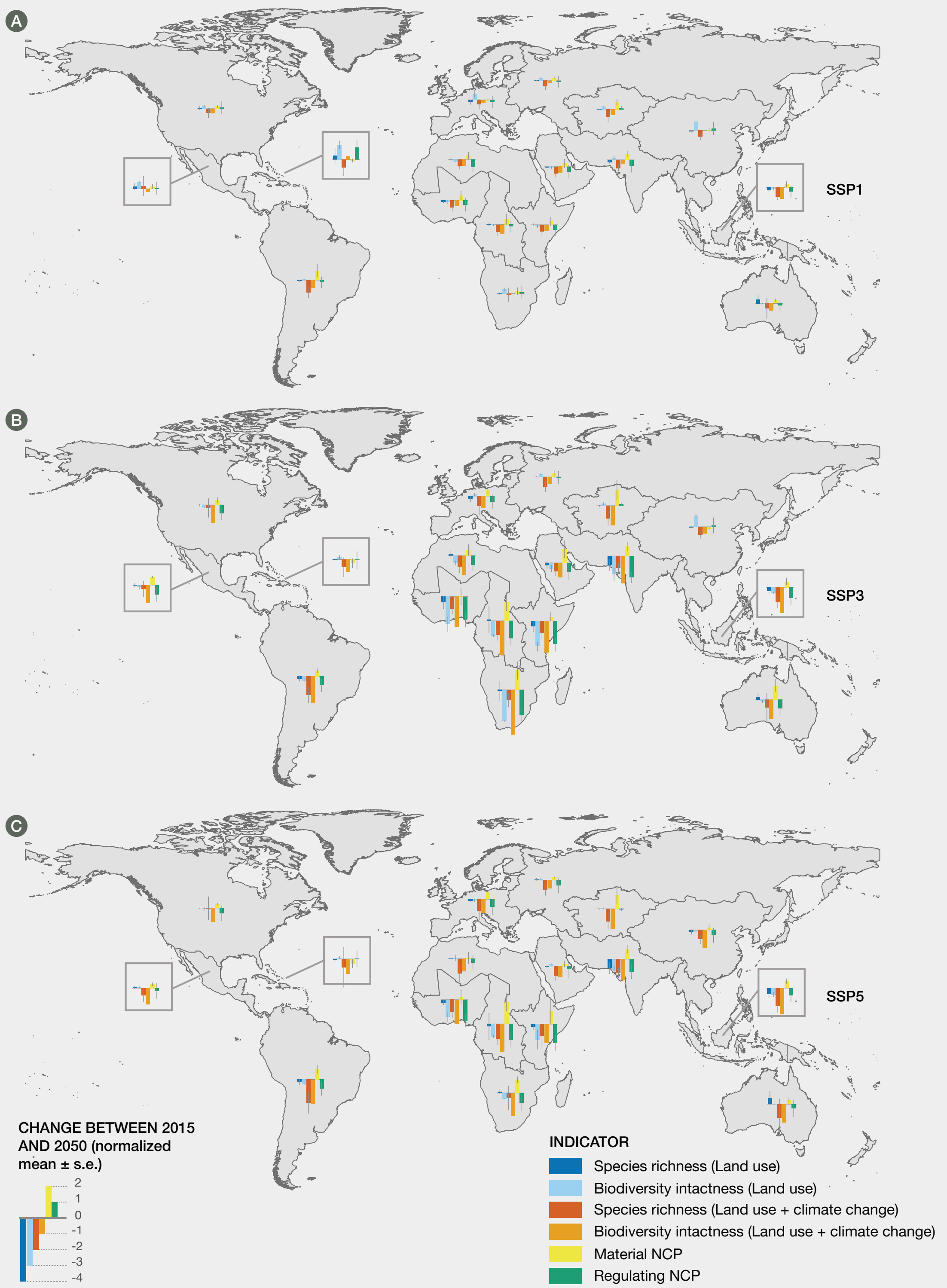


Figure 4 2 15 **Projected changes in biodiversity and nature's contributions to people for the IPBES subregions for a 'global sustainability' scenario (SSP1), a 'regional competition' scenario (SSP3) and an 'economic optimism' scenario (SSP5) between 2015 and 2050.**

To allow for direct comparison across scenarios and subregions, absolute mean values of change have been standardized by dividing the individual value of a metric by the standard deviation of all the values of that metric for all subregions in all scenarios (see Appendix A4.2.3 for details).

The projected impacts of climate change on biodiversity are much greater than land-use change in this study, but there is large uncertainty in this result. There is considerable debate concerning the relative sensitivity of species response to land use vs. climate change (Bellard *et al.*, 2012; IPBES, 2018g, 2018j, 2018h, 2018i; Pereira *et al.*, 2010). This multi-model study suggests that climate change will dominate biodiversity responses as early as 2050 for all biodiversity metrics, but this outcome needs to be treated with considerable caution for several reasons including i) very high uncertainty in models of climate change impacts on biodiversity (see error bars in **Figure 4.2.14**, and Settele *et al.*, 2014 for a discussion of uncertainties), ii) there are small differences in projected land-use change across the three scenarios compared to the range in a wider set of plausible futures (Alexander *et al.*, 2017c; Pereira *et al.*, 2010; but see Popp *et al.*, 2010) showing that the three scenarios used here cover nearly the full spectrum of land-use change in the SSP scenarios set), iii) issues related to defining land-use classes and using a very small set of land-use classes and iv) optimistic assumptions about food production increases that contribute to relatively small land-use changes while neglecting impacts of agricultural intensification (see drivers section 4.1.4).

There are high levels of uncertainty associated with these projected impacts, as is the case in other studies. There are a number of general and specific limitations to the BES-SIM results. Generally, the models used to foresee future land-use change, as well as the models of climate change impacts on biodiversity and most ecosystem services have not been well evaluated with data (Alexander *et al.*, 2017c; Ferrier *et al.*, 2016; Settele *et al.*, 2014; van Vliet *et al.*, 2016a). In addition, all models have intrinsic limitations due to underlying hypotheses and simplifications (Ferrier *et al.*, 2016). For example, none of the models of species response to climate change used in the BES-SIM study explicitly accounts for the capacity of organisms to adapt to climate change, or for species-interactions (Kim *et al.*, 2018). Model outputs have been grouped into categories of metrics, but these groupings mask important differences in interpretation of metrics from the various models (Kim *et al.*, 2018). For example, interpretation of ecosystem service indicators is challenging because they are expressed in very different units. Nevertheless, besides constituting the first comparison of a broad range of models using a common set of climate and land-use scenarios, one of the benefits of the BES-SIM study was to help to quantify some of the components of uncertainty, and while the difference between models was large for all metrics **(Figure 4.2.14)**, the overall qualitative trends were similar.

Likewise, future land-cover change scenarios and different spatial patterns that have been projected for each of the four RCPs will affect buffer zones that surround existing protected areas (Beaumont & Duursma, 2012). In most biomes modelled in this study (Beaumont & Duursma, 2012), previously unused land in buffer areas is projected to decline considerably by 2050 and more so by 2100. The projected decline in local species richness might be similar for low and high emissions scenarios, if the low emissions scenario necessitates large conversion of primary vegetation, for instance for bioenergy crops (RCP2.6; Newbold *et al.*, 2015). In contrast, a scenario focusing on globally sustainable resource use, consumption change, and associated habitat restoration indicated that both extinction risks and species losses would strongly be reduced over the next decades (Visconti *et al.*, 2016). Likewise, scenarios of increasing carbon prices as incentives to increase return from maintaining forested areas under a REDD mechanism drastically reduced local extinctions, especially in regions with high species richness (Strassburg *et al.*, 2012).

Estimates of impacts of land-use change on ecosystems and biodiversity need to consider urban areas and landscapes. Over the coming decades, some ecoregions and biodiversity hotspots will lose remaining undeveloped area through urban development, with localised large pressures on rare species and protected areas (Güneralp & Seto, 2013; McDonald *et al.*, 2008; Seto *et al.*, 2012). Nonetheless, a number of indicators of bird biodiversity differed little between urbanised and non-urbanised environments (Pautasso *et al.*, 2011). In Australia, some cities support a relatively larger number of threatened plant and animal species compared to non-urban landscapes (Ives *et al.*, 2016). With ongoing and future projected urbanisation of human societies, impacts of cities, larger urban areas and land transportation networks clearly must be included in scenarios of future biodiversity at different spatial scales.

Projected anthropogenic land-cover change and intensification of agriculture and pastures will enhance emissions of greenhouse gases. Future emissions of N_2O from terrestrial ecosystems in response to deposition and fertiliser use and climate change are projected to be enhanced by ca. 20% to threefold by the middle of the 21st century across a range of RCP (2.6, 8.5) and SRES scenarios (A1, B1, A2, B2) (Bodirsky *et al.*, 2012; Kanter *et al.*, 2016; Stocker *et al.*, 2014). Other gaseous forms of N losses (NOx and NH3) and their atmospheric reactions affect secondary organic aerosols, the lifetime of methane, or formation of tropospheric ozone (Bodirsky *et al.*, 2012; Butterbach-Bahl *et al.*, 2011; Kanter *et al.*, 2016; Lassaletta *et al.*, 2016; Zaehle *et al.*, 2015), and pollute waterways (section 4.2.3). On the other hand, land management practices in cropland, pastures and managed forests have been estimated to potentially contribute to emissions reductions by 1.5-4.8 Gt CO_2eq a-1 (Griscom *et al.*, 2017; Smith *et al.*, 2014a) achievable over few decades at carbon prices up to 100 $ US, without detrimental side effects on productivity, water use or biodiversity. This greenhouse emissions reduction potential might be tripled if food demand-side measures are also taken.

4.2.4.3 Future global ecosystem functioning and biodiversity in strong climate change mitigation scenarios

Land use is becoming increasingly central in future scenarios that target strong climate change mitigation (Popp *et al.*, 2017). Avoided deforestation (in conjunction with afforestation and reforestation, AR) is seen as one possible option (Angelsen, 2010; Chazdon *et al.*, 2016; Cunningham *et al.*, 2015; Smith & Torn, 2013; Strassburg *et al.*, 2012), which is also low-cost (Griscom *et al.*, 2017; Humpenoder *et al.*, 2014). Co-benefits of avoided deforestation for biodiversity (see **Figure 4.2.2**, Table A4.2.1 in Appendix 4.2) and local communities can be large, whereas the environmental impacts of large-scale afforestation and reforestation depend to a large degree on prior vegetation cover and the tree species planted for reforestation. Under the Paris COP21 climate agreement, forest-based climate mitigation targets feature prominently in several countries' Nationally Determined Contributions (Grassi *et al.*, 2017). Likewise, bioenergy in combination with carbon capture and storage (BECCS) has been put forward as a major land-based climate change mitigation approach in many scenarios that achieve a target of 2°C warming or below (Fuss *et al.*, 2016; see IPCC, 2018, Chapter 4.3.7; Popp *et al.*, 2014; Smith *et al.*, 2016). In Integrated Assessment Models (IAMs), the global cumulative C-uptake potential has been estimated to be ca. 55-190 GtC for avoided deforestation and AR at the end of the 21st century, and between ca. 125-250 GtC for BECCS (Humpenoder *et al.*, 2014; Tavoni & Socolow, 2013). Annual carbon uptake in 2050 for BECCS (1-2.2 GtC a^{-1}) and AR (0.1-1 GtC a^{-1}) is equivalent to up to one third to three quarters of today`s land carbon sink (IPCC, 2018, Chapter 4.3.7; Le Quéré *et al.*, 2018). In absence of carbon capture and storage, IAM projections may indicate even higher use of bioenergy (although it remains unclear how the required land area could be made available in an overall environmentally sustainable manner), unless the IAM scenarios are based on reduced energy consumptions and/or availability of cheap renewable energy, which reduces the need for land-related climate change mitigation (IPCC, 2018, Chapter 2.3). Analyses of ecosystem carbon uptake with dynamic global vegetation models (Fisher *et al.*, 2010) have arrived at consistently lower numbers than land-use models in IAMs when confronted with similar land-use change projections (Krause *et al.*, 2018). The reasons for the discrepancies in carbon uptake potential calculated with IAMs and DGVMs are not yet fully resolved. Indirect land-use changes complicate projections further. For instance, Popp *et al.* (2014) argued that stringent forest conservation policies could well lead to a spill-over effect such that land transformation for agriculture is shifted to other carbon-rich and biodiversity-rich ecosystems such as savannahs or temperate grasslands. Stringent climate change mitigation affects ecosystem productivity through bounded temperatures (and precipitation), but also via lower CO_2 in the atmosphere. Stabilizing or reducing the atmospheric concentration of CO_2 is expected to stabilize or reduce the fertilization effect of photosynthesis and is likely to also stabilize or reduce productivity compared to present-day levels (Jones *et al.*, 2016; Pugh *et al.*, 2016b).

Growth of bioenergy in simulation studies is in some cases restricted to marginal lands to avoid competing with food production, with the implicit assumption that these marginal lands would also be diversity-poor, which is not necessarily the case (Plieninger & Gaertner, 2011). The published studies mostly lack a clear definition and do not quantify the criteria used for classifying marginal or degraded land (de Jong *et al.*, 2011). Schueler *et al.* (2016) mapped the sustainability criteria, which include biodiversity protection, of the European Renewable Energy Directive to the global land area and found, for present-day environmental conditions, a potential for an additional bioenergy generation of around 80-90 EJ a-1 on ca. 430 Mha land. A large proportion of this land area is classified as low yielding (low productivity). Regions of high-yield potential that are currently under natural vegetation would be at risk for development unless protective sustainability measures are applied. In a stylised scenario experiment based on data for *Miscanthus* as a bioenergy crop species, half the potential for global bioenergy production was found to lie within the top 30% of land area classified of highest priority for biodiversity protection (Santangeli *et al.*, 2016). In a recent simulation of future land-use impacts on extinction risk of endemic species, and applying land-use change projections adopted from (Popp *et al.*, 2014), the RCP2.6-SSP1 scenario was identified as causing the least loss of natural vegetation cover by 2050 and the least extinctions of endemic mammals, birds and amphibians, compared with the – in this study – "worst case" RCP3.4-SSP4 (Chaudhary & Mooers, 2017). Climate change was not considered as an additional factor, which likely would have enhanced the projected biodiversity risk in the stronger climate change cases. The published literature overall suggests that only protective mechanisms that account for carbon storage potential and biodiversity at the same time could yield the intended carbon-mitigation objectives while avoiding degradation of diversity.

Uncertainties regarding impacts on biodiversity and ecosystems arising from different land-use change projections cannot be assessed yet. It was shown that structural differences (for instance, the type of economic model) that exist between different land-use change models can have a similarly large impact on future land-use change projections than the underlying socio-economic scenario (Alexander *et al.*, 2017c; Prestele *et al.*, 2016). However, only one Integrated Assessment Model provides the so-called marker scenario per RCP/SSP combination (Popp *et al.*, 2014; see **Box 4.2.5**). Without a larger set of harmonised historical to future land-use change projections for each of the RCP/SSP, from a wide range of different land-use change models, the degree to which impacts on biodiversity and ecosystem state and function are related to scenario archetypes remains unresolved.

4.2.4.4 Invasive alien species

Invasive alien species are a major driver of biodiversity loss today (see Chapter 2.2, section 2.2.5.2; see Bustamante *et al.*, 2018; Elbakidze *et al.*, 2018; Nyingi *et al.*, 2018; Wu *et al.*, 2018). Projections of invasive alien species all foresee continued substantial changes in biological invasion state and pressure with significant consequences for both biodiversity and human well-being. These projections have until recently been biased towards climate change related questions, but increasingly also consider how land use and trade patterns might affect future distribution of invasive alien species. Future changes of invasive alien species distributions are still uncertain, but several generalizations can be made from modelling work.

The pressure on biodiversity, and ecosystem function from biological invasions is expected to continue to grow in the coming decades in most parts of the world (Bellard *et al.*, 2013; Gallardo *et al.*, 2017; Hulme, 2009), as well as the economic damage caused by invasive alien species to society (Bradshaw *et al.*, 2016). Extrapolations of cumulative introduction events over Europe suggest that the number of invasive species will continue to increase (CBD, 2014; Elbakidze *et al.*, 2018). This trend is likely to be accentuated at a global scale, as trade between climatically and environmentally similar regions are predicted to increase and habitats continue to be disturbed (Chytrý *et al.*, 2012; Seebens *et al.*, 2015). For example, future hotspots of naturalized plants are predicted to occur mostly in North America, Australia, and South America, followed by Europe, South Africa and China (Seebens *et al.*, 2015). An analysis conducted on the IUCN "100 of the world's most invasive alien species" suggests future expansion of these species especially in cool temperate areas. The biomes with the highest expected expansion are temperate mixed forest, temperate deciduous forests and coniferous cool forests but also southern Australia, Argentina, as well as Pacific and Caribbean islands due to climate and land-use changes (Bellard *et al.*, 2013). Tropical forest and tropical woodland are projected to be less favorable for those "top invasive" species by 2080. Moreover, some regions will offer more suitable environmental conditions for survival and spread of invasive species compared to current conditions in the eastern part of the United States, northern Europe, Argentina, southern China and India (Bellard *et al.*, 2013). Indeed, poleward migrations of species are expected for many invasive alien species, leading to shifts at higher latitudes of species (Bellard *et al.*, 2013), especially in Europe where shifts are anticipating to reach unprecedented rates of 14-55km/decade (Gallardo *et al.*, 2017). Climate change might also affect establishment of new invasive species indirectly, for instance through changing patterns of human transport or by rendering existing management strategies to defend against invasive species less efficient (Hellmann *et al.*, 2008).

The potential consequences for biodiversity of these future invasions are various. One of the most dramatic consequence is local extirpation of native populations but also species extinctions on islands (Clavero *et al.*, 2009). Invasive mammal species have been a primary cause of extinctions on islands and future impact of those species on insular threatened vertebrates are predicted to increase, if no management measures are undertaken (McCreless *et al.*, 2016). A recent study focusing on Europe showed that protected areas within Europe may offer effective protection to native species against future invasions (Gallardo *et al.*, 2017). Another substantial consequence of biological invasions is the homogenization of fauna and floras which is likely to continue in the future. For instance, continental islands are projected to homogenize greatly beyond current levels of mammal assemblages, while oceanic islands are simulated to experience little additional homogenization of their mammal assemblages (Longman *et al.*, 2018). How many of future introduced species will become invasive is difficult to assess because there is generally a time lag of several decades between introduction, establishment and impact. This time lag also offers a time window for opportunities and actions to mitigate invasions.

4.2.4.5 Pollution impacts on terrestrial ecosystems: Ozone (O_3) and Nitrogen

In response to tropospheric ozone exposure, net photosynthesis declines, either due to the energy needed to produce defence compounds, or the direct damage to the photosynthetic apparatus (Feng *et al.*, 2008; Wittig *et al.*, 2009). Simulations studies result in damage of the order of approximately 10% in annual gross primary production (Franz *et al.*, 2017; Li *et al.*, 2017; Lombardozzi *et al.*, 2012; Sitch *et al.*, 2007) with feedbacks to climate by reduced terrestrial carbon sink strength (Ciais *et al.*, 2013; Sitch *et al.*, 2007). Changes in future species community composition arising from differences in species' vulnerability to ozone is not possible to project with current modelling tools, although some evidence exists that ozone indeed can affect species composition and richness (see Fuhrer *et al.*, 2016 and references therein). Large regional differences regarding ozone's future impact on plant communities, carbon or water cycling, or crop yields are to be expected (Franz *et al.*, 2017; Fuhrer *et al.*, 2016; Li *et al.*, 2017).

Eutrophication of terrestrial ecosystems has been found to affect a wide range of ecosystem functioning and community composition across ecoregions (Clark *et al.*, 2017). Nitrogen addition in experimental grassland plots reduced species richness (DeMalach *et al.*, 2017), whereas aboveground plant productivity increases across ecosystems (Greaver *et al.*, 2016). While the key processes operating in the interplay of climate change, N deposition and plant and soil physiology are rather well known, today's modelling tools are inadequate to provide process-based future projections (Greaver *et al.*, 2016). Global projections of the future C sink strength of the terrestrial biota have demonstrated large differences in models that account for C-N interactions, compared to models that ignore these (Arneth *et al.*, 2010; Wårlind *et al.*, 2014; Zaehle, 2013; Zaehle *et al.*, 2015).

4.2.5 Challenges in linking biodiversity and ecosystem functioning at the global level

Linking biodiversity quantitatively to ecosystem function, globally and across large regions, is still a challenge. Species diversity was found to correlate with productivity in (semi) natural systems and in land managed for food or timber (Duffy *et al.*, 2017; Isbell *et al.*, 2011; Liang *et al.*, 2016; Visconti *et al.*, 2018). Likewise in tropical and temperate rivers fish biodiversity correlated positively with fish yields (Brooks *et al.*, 2016). In Amazon forests, carbon storage and turnover were shown to be impacted significantly by tree-mammal interactions (Sobral *et al.*, 2017). In boreal forests, diversity and tree productivity were also correlated (Paquette & Messier, 2011). But global modelling tools to explore in marine, terrestrial and freshwater systems the futures of biodiversity or the futures of ecosystem function are still mostly disconnected (Cabral *et al.*, 2017; Mokany *et al.*, 2016, 2015; Snell *et al.*, 2014; Visconti *et al.*, 2016). This gap reflects the need for connecting model development efforts across scientific disciplines. In the marine field, for example, global scale models of ecosystem function have been mostly developed by physicists, in the form of coupled physics-biogeochemical models representing carbon and nitrogen fluxes between low trophic level functional groups (e.g., phytoplankton, zooplankton), while at the other end of the food web, fish and higher trophic level models have been developed by biologists with far more focus on life history and biodiversity, but embodying simplified forcing of climate, and less global scale perspective (Rose *et al.*, 2010; Shin *et al.*, 2010; Travers *et al.*, 2007).

Global-scale biodiversity modelling has been concerned with a sub-set of challenges, focusing on how future warming will affect the distribution or extinction of species. Interspecific interactions and multi-driver interactions are typically ignored, which can result both in over- and underestimation of risks in diversity losses (Alkemade *et al.*, 2009; Bellard *et al.*, 2012, 2013; Carpenter *et al.*, 2011; Mokany *et al.*, 2016; Pacifici *et al.*, 2015; Pereira *et al.*, 2010; Snell *et al.*, 2014; Visconti *et al.*, 2015). Little attention has been paid to global scale projections of functional, phylogenetic or genetic diversity, even though fast adaptation to environmental changes are possible through microevolution or phenotypic plasticity (section 4.2.1.2; Bellard *et al.*, 2012; Pelletier & Coltman, 2018). Likewise, DGVMS simulate ecosystem state and function, expressed as the stocks and flows of carbon, water and nitrogen (Le Quéré *et al.*, 2018), but with little consideration for interactions between and within groups of plants, or across multiple trophic levels. Potential ways forward to overcome barriers in bridging between models of ecosystem state and functioning, and models that simulate changes in diversity are being proposed in the terrestrial domain (Mokany *et al.*, 2016, 2015; Snell *et al.*, 2014). In the marine domain, integrated end-to-end models start to emerge, resulting from the coupling of disciplinary models of ocean physics, ocean biogeochemistry and fish biodiversity (Fulton, 2010; Rose *et al.*, 2010; Travers *et al.*, 2007). It is expected that approaches towards integrating models of biodiversity and ecosystem function will flourish in the future, despite the multiple technical and conceptual challenges they entail.

Large uncertainties exist both in how impact models respond to climate change and associated environmental drivers (e.g., CO_2 fertilisation, N limitations/fertilization; Ahlström *et al.*, 2012; Ciais *et al.*, 2013; Friend *et al.*, 2014; Gonzalez *et al.*, 2010; Heubes *et al.*, 2011; Huntingford *et al.*, 2009; Rammig *et al.*, 2010; Warszawski *et al.*, 2013; see also section 4.7). Regarding land-use change projections, impacts on biodiversity and ecosystems received so far much less attention compared to climate change (see 4.2.4.2, 4.2.4.3). Futures of other drivers still need to be explored despite of their known large impacts on biodiversity and ecosystems in the past, and today (pollution, invasive species). Moreover, model experiments as well as observational studies tend to concentrate on single-driver responses, despite indications that combined effects cannot be predicted from the sum of single-factor responses (Alkemade *et al.*, 2009; Fu *et al.*, 2018; Langley & Hungate, 2014; Visconti *et al.*, 2015).

Clearly, improvements of scenarios and modelling tools are still needed to be able to represent the future environmental conditions (i.e. the range of conditions that will impact on biodiversity) in a way that is comparable across direct drivers and that enable us to make a fair comparison of their expected impact in the future. For that reason, the overall issue of the relative and combined expected impacts of different drivers in the future remains unresolved.

4.3 PLAUSIBLE FUTURES FOR NATURE'S CONTRIBUTIONS TO PEOPLE

4.3.1 Nature's contributions to people across scenario archetypes

Scenarios and models are important tools for understanding how the multiple contributions of nature to people (NCP) might unfold in the future. Scenarios that are adverse for biodiversity and ecosystem function are likely to be adverse for NCP because of known links between biodiversity, ecosystem function and the material, regulating and non-material benefits to humans (Mace *et al.*, 2012). Nonetheless, there is still a lack of robust knowledge and quantitative estimates of these relationships, and thus how they might impact future changes in NCP.

Scenario archetypes were used to examine the relationship between different socio-economic development pathways and their impacts on the three broad categories of nature's contributions to people (regulating, material and non-material contributions), as interpreted mostly from the ecosystem services literature. Results from the systematic literature review of global and continental-scale scenarios (see Appendix A4.1.1) were classified as falling under "economic optimism" (75 = number of results), "global sustainability" (35), "regional competition" (59), "business-as-usual" (34), "regional sustainability" (14), and "reformed markets" (31) (**Figure 4.3.1**; see also section 4.1.3 for archetype descriptions). Overall, global and continental-scale scenarios addressing NCP are scarce and biased towards a few categories. Some NCP are relatively frequently analyzed such as food and feed, regulation of freshwater and climate;

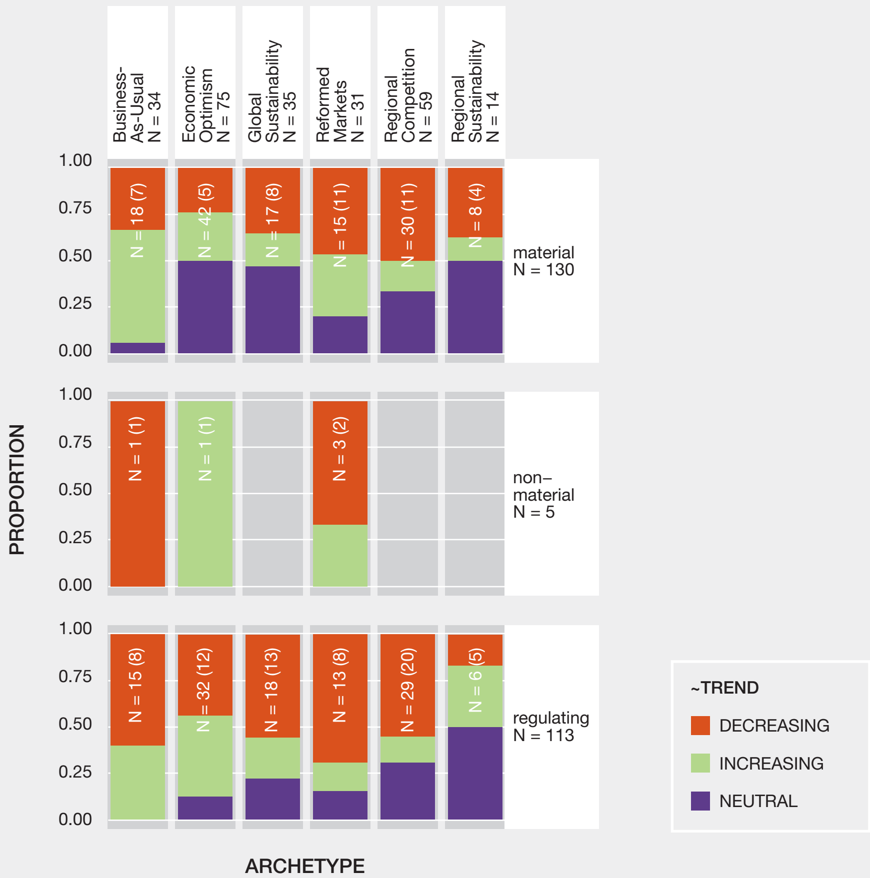


Figure 4 3 1 **Results of the systematic literature review (Appendix A4.1.1) showing the three broad groups of nature's contributions to people (material, non-material, and regulating NCP) for each of the six scenario archetypes.**

The y-axis indicates the proportion of negative and positive trends reported in the literature review. Numbers (N) indicate the number of results, followed by the number of articles that report those results in parentheses.

while non-material NCP or some regulating NCP such as regulation of the impacts of hazards and extreme events and regulation of ocean acidification are covered by a very low number of studies at continental or global scales.

It should be noted that the reviewed literature usually uses the terminology of "ecosystem services" or reports on aspects of ecosystem services without making explicit reference to the ecosystem services framework. Chapter 1 presents a detailed discussion about the relationship between ecosystem services and NCP categories. The literature has been interpreted accordingly, and ecosystem services have been reclassified into IPBES NCP categories. In this section, the term "ecosystem service" is, however, used instead of NCP when it is helpful for clarity and understanding.

4.3.2 Changes in nature's contributions to people

Regulating NCP show decreasing trends in the future in most scenario archetypes **(Figure 4.3.1)**, with only "regional sustainability" and "economic optimism" scenarios showing mixed trends for regulating NCP. "Reformed markets" and "business-as-usual" scenarios present the highest proportion of declining trends for regulating NCP. Material NCP show mixed trends along scenario archetypes. "economic optimism" is the scenario that shows the lowest number of negative trends for material NCP followed by "business-as-usual" and "Global Sustainability". In all cases, published studies focused on the supply of NCP (which is not deconvoluted with the demand of NCP) and did not take into account flows, uses, beneficiaries or values.

Figure 4.3.2 shows the trends for three NCP with the most entries in the systematic literature review database. Food and feed show a mixed picture, while regulation of climate shows a more positive picture and regulation of freshwater a very negative one. This is especially worrisome, because water is the basis for the generation of all other NCP and the direct well-being of humans.

4.3.2.1 Nature's contribution to people – regulating contributions

Habitat creation and maintenance

Habitat creation and maintenance has crucial importance for facilitating all NCP. Considering the projected increasing loss of natural vegetation cover in nearly all future land-use

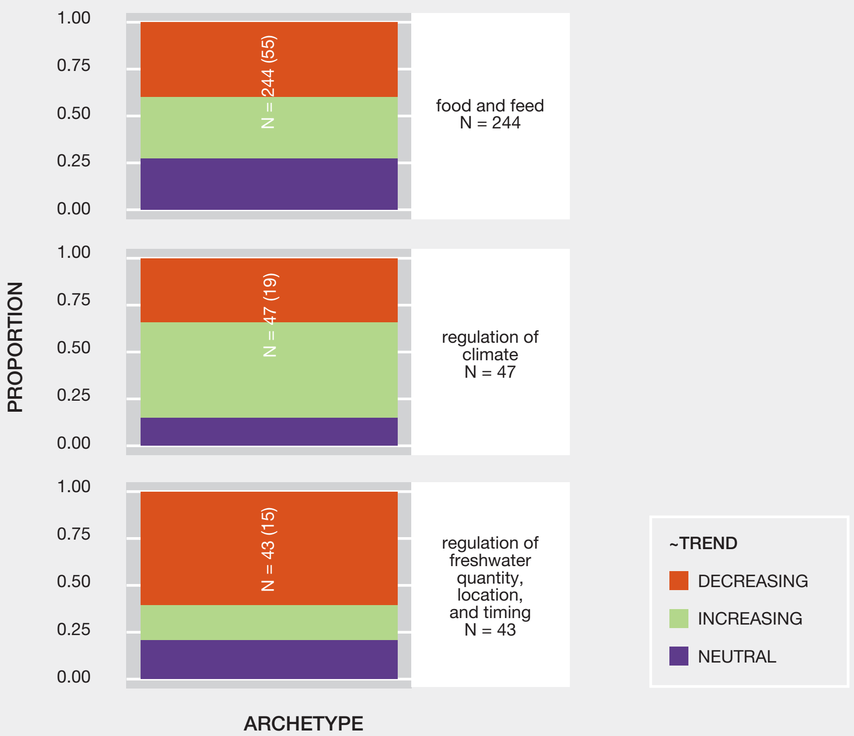


Figure 4 3 2 **Results of the literature review showing the trends for three NCP categories that are the most frequently represented in studies.**

There were insufficient entries to differentiate between archetype scenarios so this figure shows the general patterns over all scenario types.

change scenarios and the climate change induced shift in natural vegetation distribution (see section 4.2.4), it is to be expected that species with specific habitat requirements will be under increasing pressure. Homogenization of communities and habitats is expected to have negative consequences on the ability of ecosystems to maintain multiple ecosystem functions. In addition to habitat specialists, species that can be classified as being intermediate between specialists and generalists will be under increasing pressure, since these species tend to rely on intact metapopulations and are vulnerable to increasing degradation of landscapes. Their loss would have a particularly large impact on genetic diversity since generalist species tend to have more genetic variability compared to specialists (Habel & Schmitt, 2018).

Projections of future interactions between changes in terrestrial habitats and biodiversity focus either on climate change impacts, or on the transformation of natural ecosystems into agricultural systems as main drivers (section 4.2.4; Alkemade *et al.*, 2009; Bellard *et al.*, 2012; Jantz *et al.*, 2015; Mantyka-Pringle *et al.*, 2015; Pereira *et al.*, 2010; Visconti *et al.*, 2016; Warren *et al.*, 2011). At the global scale, little attention has been paid to restoration scenarios. Likewise, most biodiversity and ecosystem models do not have the capacity to represent habitat degradation and fragmentation (Bonan & Doney, 2018). Beyond the use of species distribution models, actual movement of species, either as individuals or as groups is often not taken into account in models used to project interactions between changing environments and populations (Holloway & Miller, 2017), which implies large uncertainty regarding the future vulnerability and/or resilience of habitats and their interactions with the populations these habitats sustain.

Pollination and propagule dispersal

Animal pollination and propagule dispersal play a vital role as a regulating NCP, including for food production and many other ecosystem services. Projected loss of diversity of pollinators and alteration of their communities generate risks for food security, human health and ecosystem function. Pollinators and the provision of pollination will be negatively impacted by land-use change (habitat destruction, fragmentation and degradation), intensive agricultural management and pesticide use, environmental pollution, invasive alien species, pathogens and climate change (Chagnon *et al.*, 2015; IPBES, 2016a; Vanbergen *et al.*, 2018). For instance, the spread of invasive ants that can deter pollinators and seed dispersers is anticipated to continue (see also section 4.2.4) and projected to substantially impact future pollination services (Vanbergen *et al.*, 2018). Impacts of climate change on pollinators are the most commonly reported scenario results. Under all climate change scenarios, pollinator community composition is expected to change. The projected velocity of climate change, especially under mid- and high-end emission of greenhouse gas scenarios, exceeds the maximum speed at which several groups of pollinators (e.g., many bumble bees or butterflies) can disperse or migrate (IPBES, 2016a). Differential phenological shifts can cause mismatches between plant and pollinator populations and lead to the extinctions of plant or pollinator species, with expected consequences on the structure of plant pollinator networks (Hegland *et al.*, 2009; Lavergne *et al.*, 2010; Memmott *et al.*, 2007). However, the inherent plasticity of plant–pollinator interactions suggests that many species may be able to persist, even though their mutualistic partners may change (Burkle & Alarcón, 2011).

Many management responses are available that can reduce the risks of pollination deficit in the short term, including land management to conserve pollinator resources, decreasing pollinator exposure to pesticides, and improving managed pollinator techniques (IPBES, 2016b). The disruption of propagule dispersion due to biodiversity loss is also expected to disturb ecological communities and threaten important ecosystem functions and NCP. For example, frugivore defaunation in tropical forests can lead to local extinction of trees depending on them to reproduce and the induced changes in tree species composition will likely result in the loss of carbon storage capacity of tropical forests (Bello *et al.*, 2015).

Regulation of air quality

Terrestrial ecosystems are large emitters of substances that are relevant for air quality, in particular biogenic volatile organic compounds (BVOC) and emissions from wildfires. Several studies using coupled vegetation and BVOC models show that climate change alone enhances emissions due to their temperature-dependent response (Arneth *et al.*, 2011; Niinemets *et al.*, 2010). However, land-use change is simulated to counteract these effects, in particular for compound groups isoprene and monoterpenes, since woody vegetation tends to emit more BVOC than crops. The effects of rising atmospheric CO_2 are difficult to quantify, because CO_2 enhances productivity which increases emissions, but on the other hand high CO_2 concentrations have been shown to reduce leaf-level emissions – at least for isoprene (Hantson *et al.*, 2017; Heald *et al.*, 2008; Squire *et al.*, 2014; Szogs *et al.*, 2017; Tai *et al.*, 2013). Wildfire emissions, similar to BVOC, are expected to increase in a warmer climate as fire-prone conditions are enhanced (Hantson *et al.*, 2016). In case of fire, atmospheric CO_2 enhances plant productivity, and hence combustible litter, but also leads to a shift towards more woody vegetation, which slows fire spread compared to grasslands (Hantson *et al.*, 2016; Knorr *et al.*, 2016; Rabin *et al.*, 2017). How BVOC and wildfire emissions will affect future air quality and climate regulation will depend not only on how climate change will affect biogenic emissions, but also on how anthropogenic air pollutants will alter biogenic emissions and chemical reactions in a future atmosphere (Shindell & Faluvegi, 2009; Shindell *et al.*, 2009; Tsigaridis *et al.*, 2014; Young *et al.*, 2009). Anthropogenic emission controls are much more important than biogenic emissions for air quality. However, assessments of impacts of bioenergy, reforestation and afforestation efforts on air quality and climate regulation must consider side effects of biogenic emissions on human health and on climate-related substances, as well as (in case of wildfire) the risk of forest loss (Ashworth *et al.*, 2013; Rosenkranz *et al.*, 2015; Simpson *et al.*, 2014).

Regulation of climate

Oceans and terrestrial ecosystems currently take up around 50% of anthropogenic CO_2 emissions each year (sections 4.2.2, 4.2.4; Le Quéré *et al.*, 2016). In the future, these carbon sinks may weaken, resulting in amplifying feedbacks to climate change (Arneth *et al.*, 2010; Ciais *et al.*, 2013; section 4.2.4). In oceans, warmer temperature, increased stratification of the water column, deoxygenation, and acidification, as well as sea level rise in coastal wetlands, might lead to a reduction of the sink (see 4.2.2.2.1, 4.2.2.2.2), while in terrestrial ecosystems, the interplay between CO_2-fertilisation of photosynthesis, heterotrophic respiration stimulated by warmer temperatures, and episodic events such as fire, insect outbreaks, or heat waves are controversially debated with respect to their impacts on future carbon uptake and climate regulation (Ciais *et al.*, 2013; Kautz *et al.*, 2017). Reducing greenhouse gas emissions from land cover change and land use, mostly related to human conversion of forests to crops and pastures, fertilizer use, rice production and animal husbandry could contribute notably to mitigate climate warming (Bustamante *et al.*, 2014; Smith *et al.*, 2014b, 2013; Tubiello *et al.*, 2015). Changes in vegetation cover would impact also regional temperature and precipitation. In tropical regions, deforestation is simulated to lead to local warming, as croplands tend to have considerably lower evapotranspiration. By contrast, in boreal regions changes in surface reflectance is the predominating factor and deforestation results in local cooling (Alkama & Cescatti, 2016). Therefore, in tropical regions, avoiding deforestation will contribute to reduce CO_2 emissions, as well as contribute to moderate the impact of regional warming – supporting also the maintenance of biodiversity (Alkama & Cescatti, 2016; Perugini *et al.*, 2017; Quesada *et al.*, 2017a).

Regulation of ocean acidification

Increasing atmospheric CO_2 concentrations will increase the partial pressure of CO_2 (pCO_2) and its dissolution in the surface ocean (section 4.2.2; Le Quéré *et al.*, 2016). It is expected that pCO_2 might double its pre-industrial value within the next 50 years (Eyre *et al.*, 2018; Hoegh-Guldberg *et al.*, 2017). Decreased calcification in calcified organisms due to increased acidification of the ocean is likely to impact marine food webs and, combined with other climatic changes in temperature, salinity, and nutrients, could substantially alter the biodiversity and productivity of the ocean (Dutkiewicz *et al.*, 2015; Kawaguchi *et al.*, 2013; Larsen *et al.*, 2014; Meyer & Riebesell, 2015). How species will respond to these changes depends on their capacity for adaptive responses. Many studies project the degradation of a large percentage of the world's tropical coral reefs (Albright *et al.*, 2018; Eyre *et al.*, 2018; Sunday *et al.*, 2017 section 4.2.2.2.2) and calcifying marine species like bivalves, might as well be significantly endangered due to ocean acidification (Hendriks *et al.*, 2010; Kroeker *et al.*, 2010). This is projected to impact many regulating ecosystem services and entire sectors of human activities and millions of livelihoods, both in developed and especially in developing countries that depend on fish and other marine products for their daily sustenance (Hilmi *et al.*, 2015; Mora *et al.*, 2013a). Moreover, recreational activities, as well as tourism which are among the world's most profitable industries (Rees *et al.*, 2010) are projected to decline by up to 80% in some areas due to climate change (Moreno & Amelung, 2009; USGCRP, 2008). Although local and regional-scale management strategies may build resilience in the short term, longer term resilience will further require a successful shift to a low greenhouse gas emissions scenario, e.g., RCP2.6 or RCP4.5 (Anthony, 2016).

Regulation of freshwater quantity, location and timing

Today, two-thirds of the global population live under conditions of severe water scarcity at least one month of the year and half a billion people face severe water scarcity all year round (Mekonnen & Hoekstra, 2016). World water demand is estimated to increase significantly, up to 50% by 2030 (UNDP, 2016), mostly due to population growth and lifestyle choices, such as shifting diets towards highly water-intensive foods (see section 4.5.3). Scenarios of water use foresee overexploitation, pollution or degradation of aquatic ecosystems (see 4.2.3) and the ecosystem services they provide or produce together with other ecosystems (Molle & Wester, 2009). Societal problems and new inequalities will also emerge as a result (Bruns *et al.*, 2016). The projected increases in human population and per capita consumption will likely lead to a sharpening of already existing water shortages if the demand of freshwater cannot be satisfied (Alcamo *et al.*, 2007; Murray *et al.*, 2012; Pfister *et al.*, 2011). Some estimates put demand surpassing supply significantly already in 2030 (Mekonnen & Hoekstra, 2016). Changing climate is progressively modifying all elements of the water cycle, including precipitation, evaporation, soil moisture, groundwater recharge, and run-off. But it is also expected to change the timing and intensity of precipitation, snowmelt and run-off (Murray *et al.*, 2012). Indirect effects of land-use change, such as deforestation, is also expected to increasingly affect water quality, water quantity and seasonal flows, especially in the tropics (Piao *et al.*, 2007). Many of the world's most water-stressed areas will likely get less water, and water flows will become less predictable and more subject to extreme events (Mayers *et al.*, 2009; Mekonnen & Hoekstra, 2016). The additional challenges for water security posed by poor management are expected to first become apparent in mega-cities. Increasing demands for water by agricultural, industrial and urban users, and water for the environment will intensify competition (Mayers *et al.*, 2009; Murray *et al.*, 2012; Pfister *et al.*, 2011). In order to address these challenges, water needs to be used more efficiently in agriculture (Fraiture & Wichelns, 2010) and caps to water consumption by river basin have been proposed (Mekonnen & Hoekstra, 2016).

Formation, protection and decontamination of soils and sediments

The Sustainable Development Goals related to food, health, water supply, biodiversity and climate all rely on healthy soils (Arcurs, 2017). Human activity has increased the erosion rates well above natural levels, degrading soils structurally and nutritionally and generating a surplus of sediment transport to rivers, which damages infrastructure, aquatic habitats and deteriorates water quality (Bouchoms *et al.*, 2017; Doetterl *et al.*, 2016; Li & Fang, 2016). Whether or not the eroded material decomposes rapidly or even acts as a carbon sink is still being debated (see Doetterl *et al.*, 2016 and references therein). Climate change is expected to globally exacerbate erosion rates in the future although exact rates and magnitude are poorly understood and large regional variability is to be expected (Li & Fang, 2016). Water erosion caused by overall enhanced precipitation in some regions or by extreme precipitation can be expected to increase (Bathurst, 2011; Bussi *et al.*, 2016; Hu *et al.*, 2013; Shrestha *et al.*, 2013). In a recent compilation of erosion model studies, most at catchment scale, Li & Fang (2016) found enhanced future erosion in response to climate change in 136 of 205 listed studies. Soil erosion can be effectively reduced by land management practices (reduced tillage, vegetation cover) (Doetterl *et al.*, 2016; Poesen, 2018). However, models that combine soil organic carbon cycling with modelling of degradation processes at regional to global scales do not yet exist. Therefore, scenarios of possible futures are virtually absent, and global or sub-global studies could not be found on future soil degradation, nor on soil restoration (IPBES, 2018f).

4.3.2.2 Nature's contributions to people – changes in material contributions

Energy

Ecosystems provide relatively inexpensive and accessible sources of traditional biomass energy, and therefore have a vital role to play in supporting poor populations. Bioenergy draws on a wide range of potential feedstock materials: forestry and agricultural residues and wastes of many sorts, as well as crops or short-rotation forests grown specifically for energy purposes (Smith *et al.*, 2016). The raw materials can be converted to heat for use in buildings and industry, to electricity, or into gaseous or liquid fuels, which can be used in transport. Today's global supply of bioenergy is around 10% of the total demand (Smith *et al.*, 2016). The global demand for primary energy is projected to grow across future scenarios, unless the world's energy system were to transformatively change within the coming two or three decades (IPCC, 2018, Chapter 2.3). Bioenergy is estimated to provide ca. 100-300 EJ a^{-1}, accounting for 15-25% of global future energy demand in 2050, but concerns about the sustainability have been raised even for amounts of 100 EJ a-1 or well below (Beringer *et al.*, 2011; IPCC, 2018, Chapter 2.3; Smith *et al.*, 2016). Deriving about 20-60% of total energy from energy crops would require up to a doubling of land and water resources (Beringer *et al.*, 2011).

Recent scenarios in Integrated Assessment Models that explore options to achieve global warming of 2°C or less include large-scale bioenergy for climate change mitigation (see 4.2.4.3; Bonsch *et al.*, 2016; Smith *et al.*, 2014b, 2016). Combining bioenergy with carbon capture and storage (BECCS) may offer the prospect of energy supply with large-scale net negative emissions, which plays an important role in many low-emission scenarios (Bruckner *et al.*, 2014; IPCC, 2018, Chapter 2; Tavoni & Socolow, 2013). However, there are challenges and risks entailed, as shown by an increasing number of studies, especially around potential conflicts with biodiversity and other NCP (Fuss *et al.*, 2016; Humpenoder *et al.*, 2014; Santangeli *et al.*, 2016; Smith *et al.*, 2016). The use of different sources for bioenergy production will have large impacts on the capacity of energy crop production, climate change mitigation and thus on the trade-offs with other NCP (Gelfand *et al.*, 2013). The trade-offs most often cited are with food production, biodiversity and terrestrial carbon storage (Beringer *et al.*, 2011). Food production will be impacted not only by conflicts in land use as such, but also because of rivalling water use through irrigation of bioenergy crop production (Beringer *et al.*, 2011). Also, the future benefit of CO_2 savings of bioenergy crops is not completely clear, as many studies do not include the emissions of N_2O in crop production that could offset CO_2 savings (Don *et al.*, 2012), or the long-term CO_2 emitted by land conversion or deforestation of natural vegetation to bioenergy crop areas (Don *et al.*, 2012; Krause *et al.*, 2017, 2018).

Food and feed materials

The largest anthropogenic use of land and water is related to the production of food. Also, food production is the largest component of human domination of the global nitrogen and phosphorus cycles (Bouwman *et al.*, 2013).

The drivers are both the food demand (type of diets, wealth and population size) and the food production system (productivity of the agricultural, aquaculture and livestock systems, exploitation of wild species, transport, waste). Rapid changes in dietary patterns since the end of 20th century (mainly in transitioning countries: Latin America, East Asia, others) have become a major factor in global land-use change pressures, mainly related to the increase of animal products consumption (Kastner & Nonhebel, 2010; Kastner *et al.*, 2012). In the coming decades, the increase in consumption of animal products is expected to play the strongest role in the demand of land, water, nutrients (N, P, K) and energy (and related CO_2 emissions) for food production (Alexander *et al.*, 2016; Peters *et al.*, 2016; Ranganathan *et al.*, 2016; Wirsenius *et al.*, 2010), due to the poor resource efficiency in the production of animal, especially ruminant protein. Therefore, land degradation and its impacts on food security are likely to increase, especially in developing regions with high and increasing demographic pressure, pressures from export-oriented commodity production expansion, scarce land and water resources and weak governance structures. Importantly, effects of land degradation on food security are not considered in any global scenario study (IPBES, 2018f). For sufficient land and water resources being available to satisfy global food demands during the next 50 years, water will have to be managed much more effectively in agriculture (Fraiture & Wichelns, 2010). Supplying sufficient calories and an overall healthy diet to feed the global population with sustainable production systems is a recognized challenge and will require solutions from local to global levels, addressing both food production, distribution and trade, and consumption (Foley *et al.*, 2011; Godfray *et al.*, 2010; Tilman & Clark, 2015). Closing yield gaps in many regions of the world may play a major role if done using sustainability principles for land management. This poses a large challenge as climate change has been projected to reduce crop yields in tropical and semi-arid regions; regions in which already today large yield gaps exist (Pugh *et al.*, 2016a; Rosenzweig *et al.*, 2013) and which include countries with projected fast changes in diets and population growth. There is large uncertainty in how extreme weather events, pest and diseases and atmospheric CO_2 levels will interact with yields (Deryng *et al.*, 2014; Gornall *et al.*, 2010; Rosenzweig *et al.*, 2013). Thus, it is necessary to increase productivity sustainably and at the same time reduce the vulnerability of agricultural production systems to climate change impacts.

Medicinal, biochemical and genetic resources

Because genetic diversity of crops and their wild relatives is a product of both the natural process of evolution and the biocultural process of evolution under domestication, genetic diversity is a source of, and a proxy for options for the future, and hence maintains options for the supply of ecosystem services (Bellon *et al.*, 2018; Faith *et al.*, 2017). However, if yields continue to be increased by means of intensive agriculture, then the environmental consequences would be substantial (Tilman *et al.*, 2001) and to the detriment of other NCP (section 4.5). The current diet worldwide is based on only 150 of the more than 7,000 plant species that humans have utilized historically for food (Gepts, 2006) and food supplies have become increasingly similar in composition across the globe (Khoury *et al.*, 2014).

The conservation of genetic resources from local varieties and crop wild relatives plays an important role in increasing productivity sustainably, maintaining local food security and quality, as well as in providing adaptive options for agricultural systems to grow diverse and nutritious food with fewer resources in harsh environments. For instance, cultivars based on local varieties can be grown in marginal conditions where commercial varieties do not perform well (Ceccarelli, 2009), and crop wild relatives harbor genetic adaptations to drought, pest and diseases resistance (Maxted *et al.*, 2013). Therefore, genetic diversity represents a source of options to face the increasingly uncertain and variable patterns of biotic and abiotic changes (Bellon *et al.*, 2017). Similarly, deploying sufficient genetic diversity decreases the risk of pathogens reaching epidemic levels and causing large-scale crop failure (Heal *et al.*, 2004).

Indigenous Peoples and Local Communities play an essential role in this regard both in managing key agrobiodiversity areas around the world and holding the knowledge that gives meaning to the value of such diversity. Maintaining in-situ crop genetic diversity is at present done mostly by smallholders and indigenous communities, cultivating local varieties individually in small-scale mosaic production systems, but these constitute in many regions large effective systems in providing food to large regional populations within a wide range of environmental conditions and cultural preferences (Bellon *et al.*, 2018; Enjalbert *et al.*, 2011). If trends towards replacing local varieties with genetically homogeneous materials of the private sector continue (Heal *et al.*, 2004; Howard, 2009), evidence suggests that while crop production yield may increase (particularly for crops destined to industrial uses and fodder), food security may be compromised not only in terms of lower crop production of food crops, but also in the form of higher risk and vulnerability of farmers and the food system to future challenges.

4.3.2.3 Nature contributions to people – changes in non-material contributions

The results of the systematic literature review highlight the scarcity of global or continental scale scenarios addressing non-material contributions to people: these have received far less attention than material and regulating NCP. Even on the local scale, the number of scenario studies dealing with the category of cultural ecosystem services is limited.

The sections below describe how different non-material NCP might unfold in the future based on scenario studies at different scales, including some local studies. In order to arrive at a better understanding on how changes in nature and changes in people's demands interact for all NCP, future studies that target non-material NCP are needed.

Learning, artistic, scientific and technological inspiration

The published literature on the future evolution of this category of NCP is scarce with most studies focusing on the current state of nature-inspiration for learning, the arts, science and technology. Nature inspiration for the arts, including music, painting and literature comes ultimately from the fact that we are part of nature, and that when we are amazed by certain aspects of nature, this inspires individuals to express their creativity (Komorowski, 2016). Whether the ongoing disconnection of humans from nature (Soga & Gaston, 2016) will affect how art is inspired by nature in the future is unresolved. Nature-inspiration has advanced technology in multiple ways, the Lotus effect or the shark skin effect being some of the most common examples (Bhushan, 2016). Nature inspiration has played a significant role in computation and communication and it is likely that it will continue doing so (Vinh & Vassev, 2016). The self-organized architecture of nature can play a major role in nature-inspired algorithms and computing (Yang, 2014, 2010). Bioinspiration and biomimetics in engineering and architecture has a long history of application, but its future development is uncertain (Ripley & Bhushan, 2016).

Physical and experiential interactions with nature

Connections to nature have been classified as being material, experiential, cognitive, emotional, and philosophical (Ives *et al.*, 2018). Partially as a result of rapid urbanization (see section 4.3.3 and Jiang & O'Neill, 2017) some argue that urbanites are undergoing an "extinction of experience" resulting from decreasing contact with nature in everyday live (Soga & Gaston, 2016). Although varying significantly across and within regions, interactions with nature have been changing from direct subsistence interactions (i.e. through agriculture, farming, fishing, hunting, herding, foraging) to sporadic subsistence, leisure, education, or as health-recommendation. This trend is expected to continue in the future although other forms of interaction with nature are also emerging, such as increasing attention to urban parks, river and lake restoration projects, urban gardens, and increasing green infrastructure in cities (Grimm & Schindler, 2018; Shanahan *et al.*, 2015; Thompson *et al.*, 2008). Indicators to assess interactions with nature are scarce. Visits to protected areas have been estimated at 8 billion per year (Balmford *et al.*, 2015) with a generally increasing trend (except for some developed countries (Balmford *et al.*, 2009), but it is unclear how this figure will evolve under different scenarios. Apart from protected areas, direct interactions with nature occur in many non-protected landscapes, from urban parks, to rural areas and remote landscapes. These interactions are more widespread than visits to protected areas and happen continuously.

The main drivers expected to affect future physical and experiential interactions with nature through nature tourism are demographics, urbanization, climate change, technology, psychological drivers, health care trends and development (Frost *et al.*, 2014). A warmer future may increase the visits to protected areas, especially to mountain protected areas where temperatures are cooler (Fisichelli *et al.*, 2015; Steiger *et al.*, 2016). In some areas, a business-as-usual scenario might reduce our interactions with nature due to the loss of natural ecosystems through deforestation. Local scenarios in the Eastern Arc Mountains in Tanzania show that non-sustainability pathways would also reduce ecotourism (Bayliss *et al.*, 2014). Participatory scenario planning approaches in which stakeholders co-develop different scenarios have been used in several local studies and assessed future trends of diverse non-material NCP such as interactions with nature (Oteros-Rozas *et al.*, 2015). Future trends for ecotourism, for example, were analyzed through the integration of ILK and scientific knowledge for a case study in Papua New Guinea (Bohensky *et al.*, 2011b).

Symbolic meaning, involving spiritual, religious, identity connections, social cohesion and cultural continuity

Among the very few existing scenario-based studies that specifically focus on this nature's contribution to supporting identities (Díaz *et al.*, 2018), some focus on sense of place, which is highly relevant for ecosystem service stewardship and for human well-being, particularly of IPLCs (Masterson *et al.*, 2017). Some analyses suggest that climate change might negatively affect sense of place (Ellis & Albrecht, 2017), an issue of concern to an increasing number of people living in coastal areas and under increasing risks such as floods and sea level rise will increase (Neumann *et al.*, 2015). Sense and forms of attachment to place are also negatively affected by changes caused by infrastructural responses, such as the need to construct flood defenses (Clarke *et al.*, 2018).

Identities that are linked to nature, such as those related to cultural keystone species, will probably decline under certain scenarios (Garibaldi & Turner, 2004). In business-as-usual scenarios indigenous identities are expected to decrease, as these are often linked to nature, and Indigenous People´s spiritual beliefs (Dudgeon *et al.*, 2010). Hunting practices that have deep cultural meanings for some local communities and help to bound some societies might be affected as well (Luz *et al.*, 2017). In cities, declining green space might produce feelings of loneliness and shortage of social support (Maas *et al.*, 2009). Connecting theories and tools related to sense of place within broader socio-ecological systems research is expected to enhance our understanding as to how and why people engage in solving challenges related to sustainable use of ecosystems (Masterson *et al.*, 2017).

Preservation of biodiversity and ecosystems, as options for the future

One of the challenges posed by the expected continuous degradation of ecosystems and loss of biodiversity in most scenario archetypes is to assess the implications of these trends in terms of options for the future (Pereira *et al.*, 2010 and see section 4.2). Local level examples **(see Box 4.3.1)** highlighting the interdependence between nature, indigenous and local knowledge, and local livelihoods provide powerful stories about economic-environmental trade-offs and the importance of maintaining options, including in terms of complementary knowledge systems, in times of accelerated environmental and social changes.

Box 4 3 1 **An example of the role of Indigenous Local Knowledge in sustaining ecosystem services.**

The shea tree is highly valued by rural households in Western and Central Africa. The shea fruit is a non-timber forest product that is indigenous to ecosystems in semi-arid regions of Africa (Jasaw *et al.*, 2015). Shea is exported as raw kernels or as shea butter to serve the high-value cosmetic and personal care industry and the wide range of food products in USA, Europe, and Japan. It currently grows throughout semi-arid northern Ghana (CRIG, 2007; Naughton *et al.*, 2015), with almost every rural household in the region engaging in shea fruit picking, and processing into shea kernels (shea nuts) and/or shea butter. For years, local populations have followed local knowledge, norms and practices including not using shea for fuelwood and integrating it into farmlands to preserve and manage it (Jasaw *et al.*, 2015). In recent years however, high disregard for indigenous knowledge practices, degradation and subsequent scarcity of traditional fuelwood tree species, and fluctuating world market prices for shea products, have pushed locals being faced with the dilemma of still preserving the tree to enable them earn income or cut the trees for fuelwood (Boafo *et al.*, 2016; Jasaw *et al.*, 2017). If current trends continue, the co-production of the shea butter will continue eroding indigenous and local knowledge (ILK), the management of common resources, as well as regulating and non-material contributions from nature to people. Both technological improvements (such as improved stoves) and the strengthening of community-based woodland management (such as harvesting tree branches instead of whole trees) need to be put in place to revert this trend (Boffa, 2015; Jasaw *et al.*, 2017, 2015).

Figure 4 3 3 **Woman taking shea harvests home to process.**

Photo credit: Yaw Boafo, 2014.

Figure 4 3 4 **Woman sorting shea kernel for sale in Northern Ghana (left); Shea kernel being dried after picking from the wild in Northern Ghana (right).**

Photo credit: Yaw Boafo, 2014.

Future scenarios of climate change predict in this case an increased climate suitability for the shea tree (Platts *et al.*, 2010). This could open certain opportunities to adapt to climate change and at the same time reinforce the value of ILK in landscape management. Since the traditional form of Shea butter production also requires large amounts of energy (Jasaw *et al.*, 2015), six scenarios of future development of technologies were developed for Burkina Faso (Noumi *et al.*, 2013). The improvement of the energy systems would result in better incomes for women and reduced vulnerabilities of rural families whilst minimizing land degradation and enhancing carbon sequestration potential of savannah landscapes.

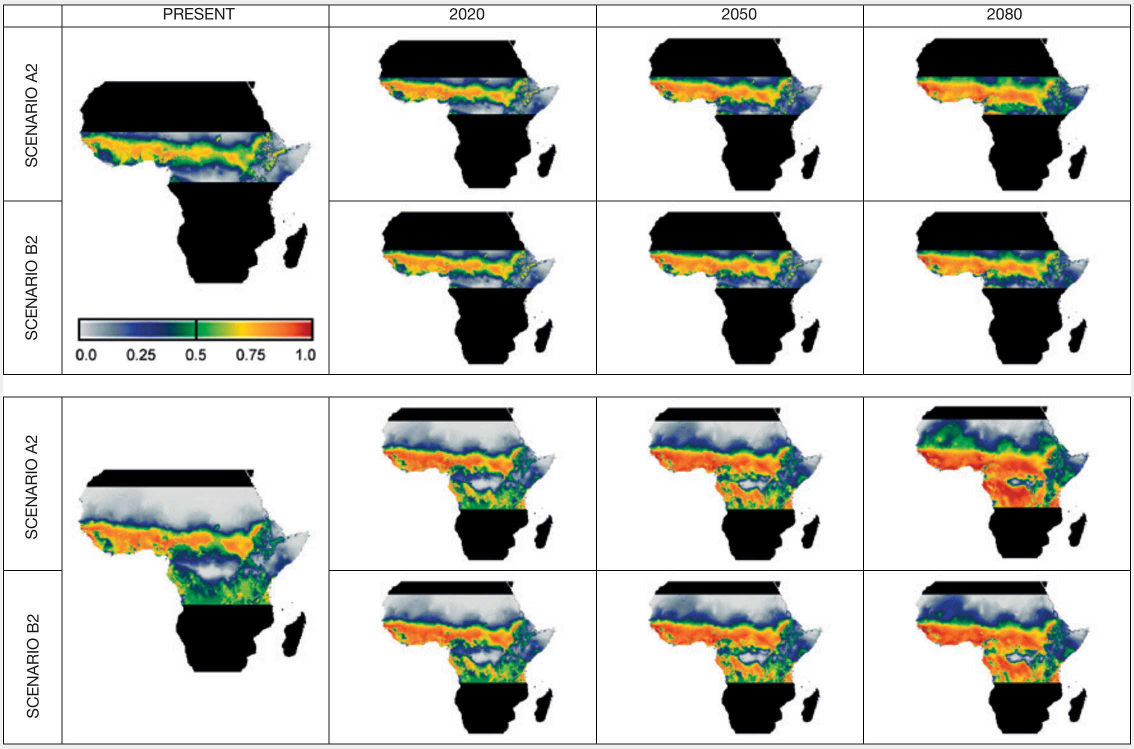


Figure 4 3 5 **Present situation and future scenarios of the climatic suitability for the distribution of the shea tree.**

In both scenarios, niche-based models predict an enhanced climatic suitability for the shea tree during the 21st century (Platts *et al.*, 2010). Top panels are projections based on a restrained geographical range for model calibration and lower panels are based on a broader geographical range. The suitable habitat for the shea tree in central Africa is projected to increase in two explored IPCC scenarios (A2 and B2) in 2020, 2050 and 2080. According to these scenarios, the maximum suitability is predicted for 2080.

4.3.3 How changes in nature's contributions to people will manifest in different regions, including teleconnections across regions

Ecosystems and biomes (or IPBES units of analysis) are interconnected, influence each other and thus many NCP are also interconnected in space (Álvarez-Romero *et al.*, 2018; Liu *et al.*, 2015). These interactions can occur in the natural system (e.g., via the atmosphere, or through river flows), often called teleconnections. In socio-economic and socio-ecological systems the telecoupling concept considers interactions, feedbacks and spillover between different and typically distant system components (e.g., by trade or migration; Güneralp *et al.*, 2013; Liu *et al.*, 2013; Melillo *et al.*, 2009). Through those mechanisms, resource use and ecosystem management in some regions affects NCP from other regions (Pascual *et al.*, 2017; see section 4.5 and Chapter 5). For example, the displacement of timber extraction from Finland to Russia has created environmental impacts in Russia that in turn affected migratory birds in Finland (Mayer *et al.*, 2005).

Knowledge about the interaction, feedback and spill-overs among regions, and implementation in future global scenarios is needed for better projections and management of NCP including flow-based aspects of governance beyond the classical territorial approaches (Liu *et al.*, 2013; Sikor *et al.*, 2013). Without such knowledge, decisions on the management of NCP in one region will lead to incomplete and skewed conclusions that affect sustainability at the global level (Schröter *et al.*, 2018). For example, telecoupling is linked to remote, large-scale investment in land purchase or lease and freshwater demand, which is happening in all continents except Antarctica (Rulli *et al.*, 2013). Also in context of urban-rural relations this consideration can help to better understand interactions with systems beyond their boundaries (Seto *et al.*, 2012).

Urbanization is one of the global development trends that has large impacts on local and distant socio-ecological systems. The global urban population represents now 55% of the total population and is projected to reach 6.6 billion by 2050 (68% of the total population) (https://population.un.org/wup/).

In the vicinity of cities, urban growth leads to the loss of agricultural land and hence agricultural production, and associated land-use displacement to other regions as compensation. Overall it is estimated that, due to urban build up, 1.8–2.4% of the global croplands will be lost by 2030 (Bren d'Amour *et al., 2017*). On local and regional level urban areas modify climate through the urban heat island effect, impacting also human health. In combination with altering of precipitation patterns, the heat island effect will possibly also have significant impacts on net primary production, functions of ecosystems, and biodiversity in larger urban regions (Seto *et al., 2013*). Urbanization also frequently correlates with lifestyle and dietary changes towards more meat and fish (Satterthwaite *et al., 2010*). As a result, long-distance connections intensify as demand for resources increases to support these urban lifestyles and activities. Often such change in demand is not only met by intensification but also by cropland expansion into semi-natural or natural vegetation (DeFries *et al., 2010*), which in turn may lead to the displacement of local farmers due to loss of land and increases migration to urban areas.

There are very few global scenario studies of telecouplings, and the related interactions between nature and NCP. For instance, most forward-looking studies on impacts of urbanization on ecosystems focus on impacts on biodiversity and habitats (Güneralp *et al.*, 2013). There are no quantitative studies and scenarios that assess interactions of urban areas with ecosystem services at global and large spatial scales and there are only a few, mostly scenario-based, regional studies from developed countries (Deal & Pallathucheril, 2009; Eigenbrod *et al.*, 2011; Norman *et al.*, 2010; Pickard *et al.*, 2017). Virtual water import/export has been explored under future scenarios under climate change, stressing local water losses due to trade links (Konar *et al.*, 2013; see also Chapter 5). For instance, continued increased consumption of meat or milk in China would have negative consequences on the virtual water imported by the country (Zhuo *et al.*, 2016), as well as higher greenhouse gas emissions and land use in milk exporting regions (Bai *et al.*, 2018). Results from the systematic literature review regarding future trends of various NCP in different world regions and the interlinkages between them do not show clear trends for many NCP because of the limited number of studies **(Figure 4.3.6)**. Mixed trends prevail for regulating NCP in most parts of the world, with slightly more increasing trends in North America, Europe, and Australia. Material NCP are expected to mainly decrease in Central America, in Southeast Asia and Australia, stabilize in South America, South Asia and East Asia; a higher proportion of increasing material NCP are expected in Europe and North America. Not much data on non-material NCP is available but positive trends in Africa and Asia could emerge, while in South America the expected trends were mostly negative.

In addition to the systematic literature review, we reviewed the IPBES regional assessments (IPBES 2018a, b, c, d) for relevant information of future trends of telecoupled interactions.

The IPBES regional assessment for Europe and Central Asia (IPBES, 2018i) highlights a variable but generally decreasing supply of regulating NCP in Europe (Harrison

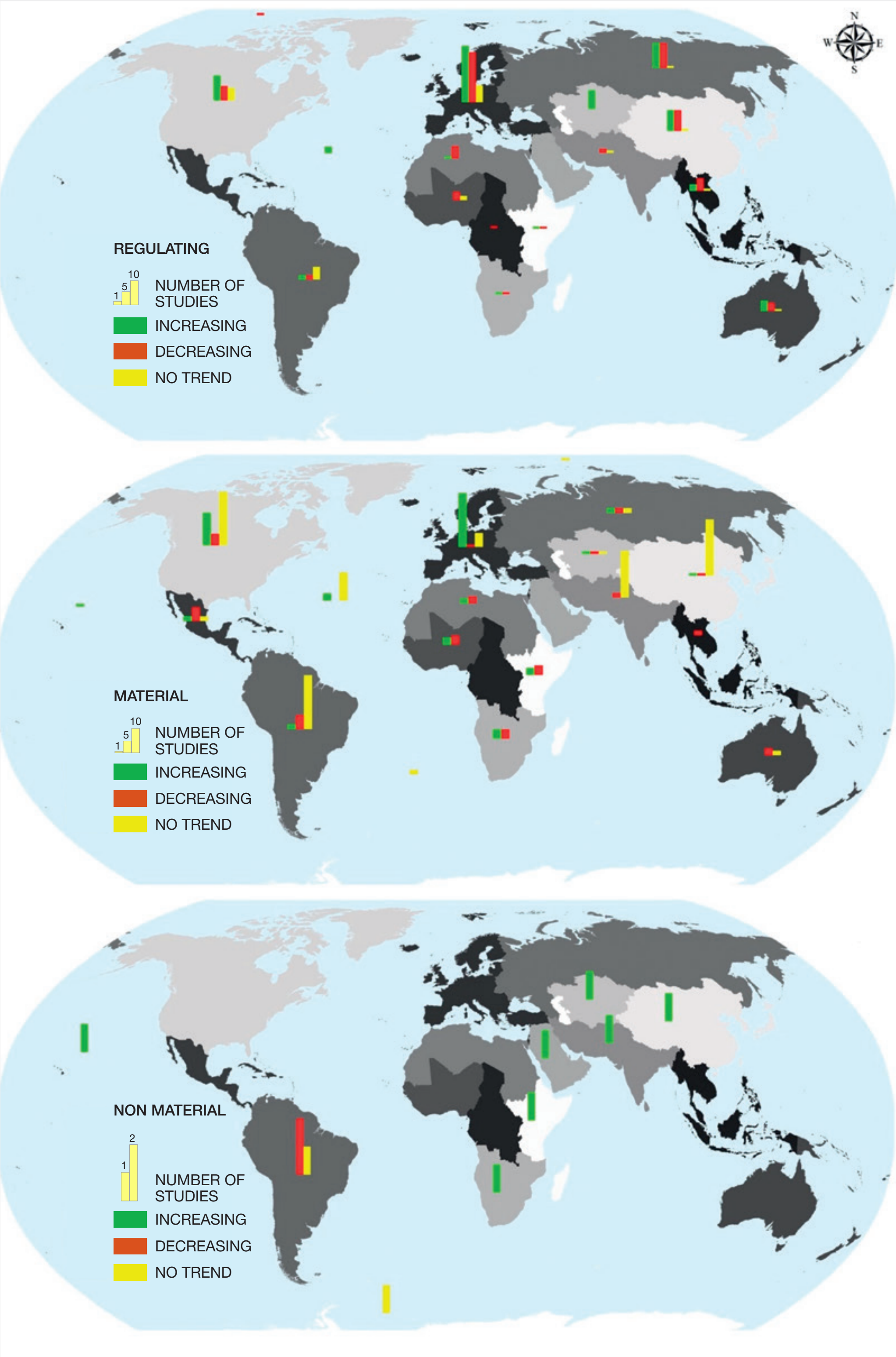


Figure 4 3 6 **Future trends of NCP in the different world regions.**

The height of the bars indicates the number of studies. The color of the bars shows the sign of future trend of NCP in the different world regions (IPBES regions shown in grey scale). Results are based on the systematic literature review of future scenarios (Appendix A4.1.1) at the continental scale. Only the studies with an explicit distinction of NCP trends between countries or regions were selected.

et al., 2018). Hazard regulation, climate regulation, water quality and quantity regulation show stable or increasing trends, whereas regulation of freshwater quantity, location and timing decreases, especially in Southern Europe. Pollination and pest regulation indicate mixed trends. Regarding material NCP, the results vary across subregions. An increase of food and feed is expected in western Europe due to increasing imports from other world regions (Dunford *et al.*, 2015). Eastern Europe and Russia show increasing trends in food production, due to the increase in suitability for food production following climate change (Zabel *et al.*, 2014). Information on non-material NCP is scarce (Harrison *et al.*, 2018).

The demand of material NCP in Europe, especially food and feed, materials and energy could increase up to 1.5-2 times, which not only means an increase in material NCP but will have considerable trade-offs with biodiversity and regulating NCP (Harrison *et al.*, 2018). According to the BAU scenario, food production will be the economic sector with the largest impact on biodiversity, possibly contributing to 60-70% of terrestrial biodiversity loss and 50% in freshwater systems (Kok *et al.*, 2014; van Vuuren *et al.*, 2015). Other scenarios, such as the global technology, decentralized solutions and consumption change would result in preventing more than half of the loss of the biodiversity that is projected for 2050. Other models show that domestic greenhouse emissions can be reduced affordably by 40% in 2030, but would require strong policies and binding targets, and possibly the use of biofuels, which have associated negative effects on biodiversity (Harrison *et al.*, 2018).

In Africa a lack of studies that assess the future of NCP is apparent and the few existing ones focus on Southern and East Africa (Biggs *et al.*, 2018). The systematic literature review shows that in different regions of Africa, the demand for food and feed will lead to an increase of this NCP, despite the pressure arising in many regions from climate variability and change (Palazzo *et al.*, 2017). Scenarios show that increased water stress will have most adverse effects on food production, as areas suitable for agriculture along the margins of semi-arid and arid areas are expected to decrease (Biggs *et al.*, 2018). An estimated 600,000 km^2 of arable land could be lost with 800 million people facing physical water scarcity. Rising sea levels will pose threats to Gambia around to the Gulf of Guinea and a predicted band of desiccation will wrap around the Congo Basin from the Gambia to Angola (Biggs *et al.*, 2018). Given the general trade-off between material and regulating NCP, a decrease in the supply of regulating NCP is expected. In Sub-Saharan Africa, bans on food imports would negatively impact poverty (Bren d'Amour *et al.*, 2016).

Existing scenarios with information for NCP in the Americas focus on the strong competition among land uses, primarily agricultural lands and natural land cover (Klatt *et al.*, 2018). The demand for food and feed will increase in the future with strong trade-offs for regulating NCP (e.g., water quality, increased greenhouse gas emissions, disruptions of natural pest control, pollination, and fertility and nutrient cycling; Diaz & Rosenberg, 2008; Matson *et al.*, 1997). Co-benefits may occur, like e.g., incorporating biodiversity in agricultural production systems (Baulcombe *et al.*, 2009; Chappell & LaValle, 2011; Clay *et al.*, 2011; de Schutter, 2011; Perfecto & Vandermeer, 2010). The supply of regulating NCP provided by natural ecosystem decreases under all scenarios (even under conservation scenarios), especially through tropical deforestation in Latin America, which is projected to continue. A similar pattern can be observed also for other ecosystems, like tundra, mangroves or wetlands. The decrease in supply of regulating NCP means that the tundra may convert from a carbon sink into a carbon source under the temperature increase that thaws the permafrost, leading to a feedback to accelerated climate change and sea level rises. The same applies for the prevention of soil erosion, coastal protection and fisheries support of mangroves. Also, the regulating services of wetlands may get traded by agricultural productions under the strong increase of population and other market forces. An example is the Amazon forest, where especially cattle ranching together with agriculture leads to deforestation, leading to a synergistic drying up of large parts of the watershed due to climate change (Klatt *et al.*, 2018).

In the Asia-Pacific region, expansion of urban industrial environments, consumption patterns and transformation of agriculture in favor of high yielding varieties and cash crops are the main drivers for changes in NCP, considering the current rate of human population growth (Gundimeda *et al.*, 2018). The demand for material NCP is projected to increase, especially for food and feed in Southeast Asia and South Asia, leading to deforestation for monocrop plantations of oil palm, rubber or timber trees. This may lead to a decrease in the supply of some regulating NCP, and natural habitats in the Asia Pacific Regions are likely to be adversely affected in the coming decades (Gundimeda *et al.*, 2018). Telecouplings are very pronounced, especially within Southeast Asia (e.g. Vietnam- Laos) and between mainland Southeast Asia and North Asia, as between Southeast Asia and Latin America and Africa. Regarding other regulating NCP the results are mixed with increases and decreases in all subregions (IPBES, 2018h).

4.4 PLAUSIBLE FUTURES FOR GOOD QUALITY OF LIFE

4.4.1 Linking good quality of Life to nature and nature's contributions to people

Global scenarios of biodiversity and ecosystem services have paid scarce attention to plausible futures for people's good quality of life (GQL), relative to those for nature and nature's contributions to people (but see Butler & Oluoch-Kosura, 2006). This gap is further pronounced for the analysis of future trends for the quality of life of Indigenous Peoples and Local Communities (IPLCs), who have been addressed typically at local and subnational scales rather than at the regional to global scales. However, a recent assessment of scenarios and models of ecosystem services and biodiversity brought to light some of the plausible futures of GQL (IPBES, 2016b), while earlier assessments highlighted the dependency of human beings on ecosystems for well-being and socio-economic development (MA, 2005; UK National Ecosystem Assessment, 2011).

To complement these efforts, in this section we seek to show how good quality of life has been integrated in the assessment of plausible futures of nature and nature's contributions to people. To this end, we address how eleven key material and non-material dimensions of GQL (see also Chapter 1) are expected to evolve under the different archetype scenarios, and highlight the role of access, social values and other factors mediating the relationship between nature's contributions to people and good quality of life.

4.4.1.1 Key Dimensions of good quality of life and their links to nature and nature's contributions to people

4.4.1.1.1 Material dimension of good quality of life

In future scenarios governed by market forces (e.g., economic optimism, business-as-usual; see Section 4.1), multiple dimensions of good quality of life (GQL), both material and non-material, can be expected to decline **(Figure 4.4.1)**. These projections are based on narratives associated with specific archetype scenarios, with numeric scores above zero indicating an anticipated positive (increased) GQL for the selected indicator, and negative indicating a decline. Projected declines are particularly pronounced for material indicators relative to livelihood and income security. The regional competition scenario, in particular, is assumed to be associated with the lowest expected GQL outcomes. On the other hand, the regional sustainability and reformed economic markets scenarios are expected to result in improved GQL outcomes across a large cross-section of material and non-material indicators. Overall, the global sustainable development and regional sustainability scenarios are associated with the most desirable GQL outcomes. Scenarios of direct and indirect drivers of change are expected to have regionally differentiated impacts on GQL, including where Indigenous Peoples and Local Communities (IPLCs) are located (see examples below). Many IPLCs are found in protected areas and indigenous areas where dimensions of a GQL such as food and energy security play out in context-specific ways. Indirect drivers of change such as climate mitigation policy (e.g., REDD+) disproportionately impact the possible trajectories towards achieving GQL by IPLCs (sections 4.1.4, 4.1.5).

Food and nutritional security

The 2018 annual report on the State of Food Security (http://www.fao.org/state-of-food-security-nutrition/en/), assessed that world hunger is on the rise again with the number of undernourished people having increased to an estimated 821 million (2017), compared with 804 million in 2016 and 784 million in 2015, although still below the 900 million reported in 2000. Future projections raise important concerns about global food security and indicate widespread disparity in its outcomes, estimating that between 5 million and 170 million people will be at risk of hunger by 2080 (Schmidhuber & Tubiello, 2007). With continuing urbanization of the global population (see section 4.3.3), much of this burden can be anticipated to be borne by the urban poor, especially in the developing south. Food security is related to cultural rights and human rights, and to processes of community change such as out-migration and livelihood shifts (e.g., changing migration patterns may leave fewer young people to hunt and fish, and elders often too old to engage in these activities). Access to resources (including financial resources) are also needed to participate in traditional activities securing access to food. Future food security scenarios refer to at least one of the four key dimensions of food security: availability, access, utilization and stability (FAO, 1998). All four dimensions are expected to be affected by climate change, although only food availability is commonly considered by simulation studies with a wide projected range of impacts across regions and time depending on the socio-economic context (Brown & Funk, 2008; Schmidhuber & Tubiello, 2007). The systematic literature review conducted in this chapter (Appendix A4.1.1) portends strong negative trends for food security in future scenarios **(Figure 4.4.3)**. The IPCC Special Report on Emission Scenarios (SRES) depicted cereal production, cereal prices and food security under three conditions: no climate change, climate change with CO_2 fertilization effects, and climate change without

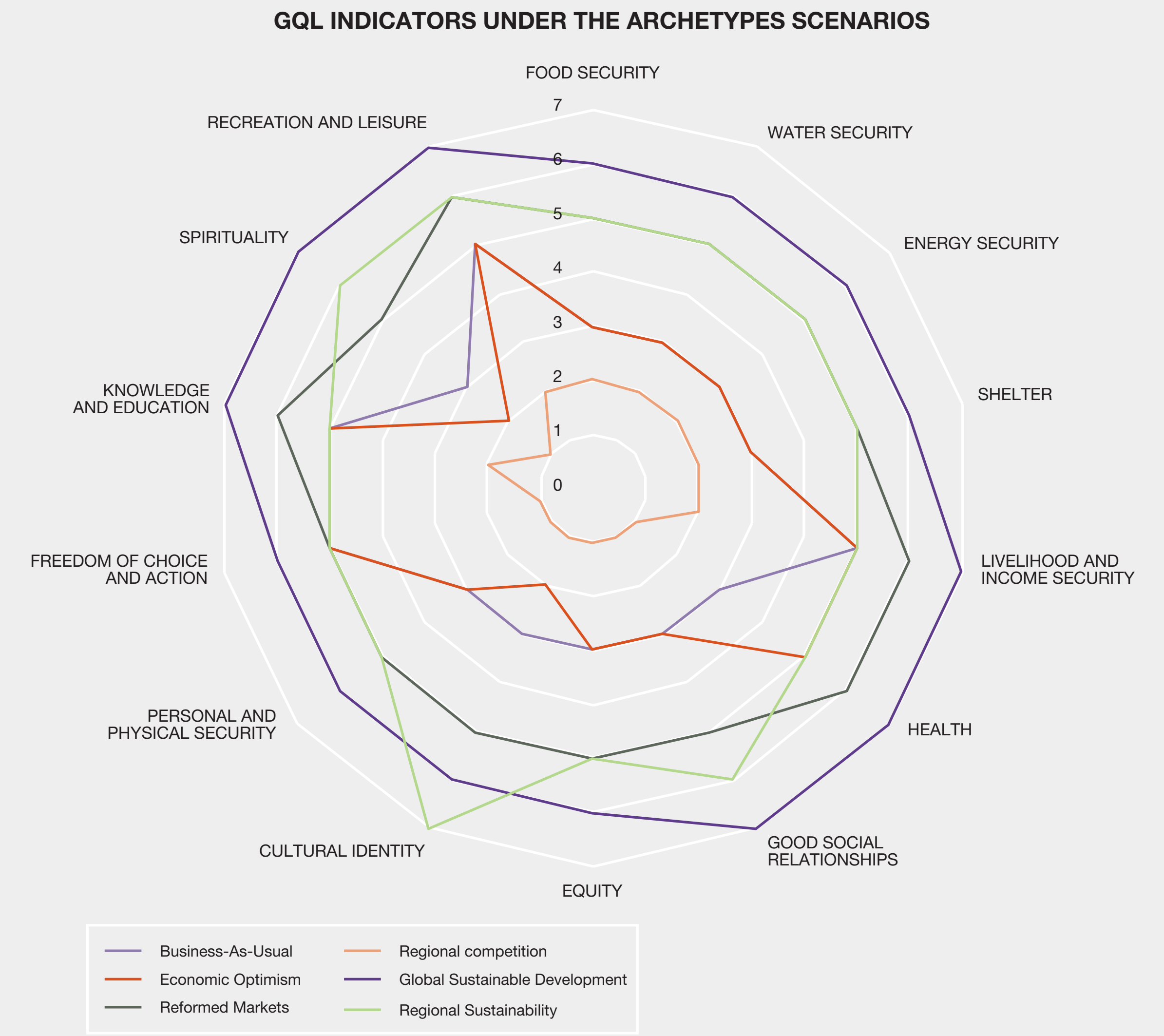


Figure 4 4 1 **Dimensions of Good Quality of Life (GQL) under archetype scenarios based on the narratives of these scenarios, taking also into account Table 6.3 of the IPBES methodological assessment of scenarios and models of biodiversity and ecosystem services (Cheung *et al.*, 2016).**

The numerical scale (-2.5 to 2.5) refers to the progress from "very negative" status = -2.5 to "very positive" status = 2.5 in the corresponding GQL indicator. More detailed information is found in the Appendix, Table A4.4.1.

CO_2 fertilization effects (Parry *et al.*, 2004). Under the assumption of no climate change and increasing yields due to technological change, it was estimated that cereal prices would increase due to an increase in global income. With climate change, food shortages were expected to drive up food prices. The MA scenarios projected an increase in total and per capita food production but variation in food prices, calorie availability and child malnutrition were also to be expected (Carpenter *et al.*, 2006). More recent work agrees that the impact of climate change on food security varies across time, space and subpopulations. For instance, food insecurity is expected to be more severe in the Amazon floodplains (Oviedo *et al.*, 2016; Vogt *et al.*, 2016), polar regions such as the Arctic Bay (Pearce *et al.*, 2015) and the Pacific Islands (McMillen *et al.*, 2014). Small-scale farming, fishing and other communities that depend directly on local environments for food production (McDowell & Hess, 2012) especially in developing countries, indigenous communities (Huntington *et al.*, 2016), or First Nations (Golden *et al.*, 2015) are particularly vulnerable to climate-related food insecurity. A synthesis across a number of international assessments integrated and grouped factors impacting food security **(Figure 4.4.2)** and identified that in these assessments the individual factors underpinning food security were mostly not linked to other relevant factors, i.e. indicating substantial gaps in our understanding of the food

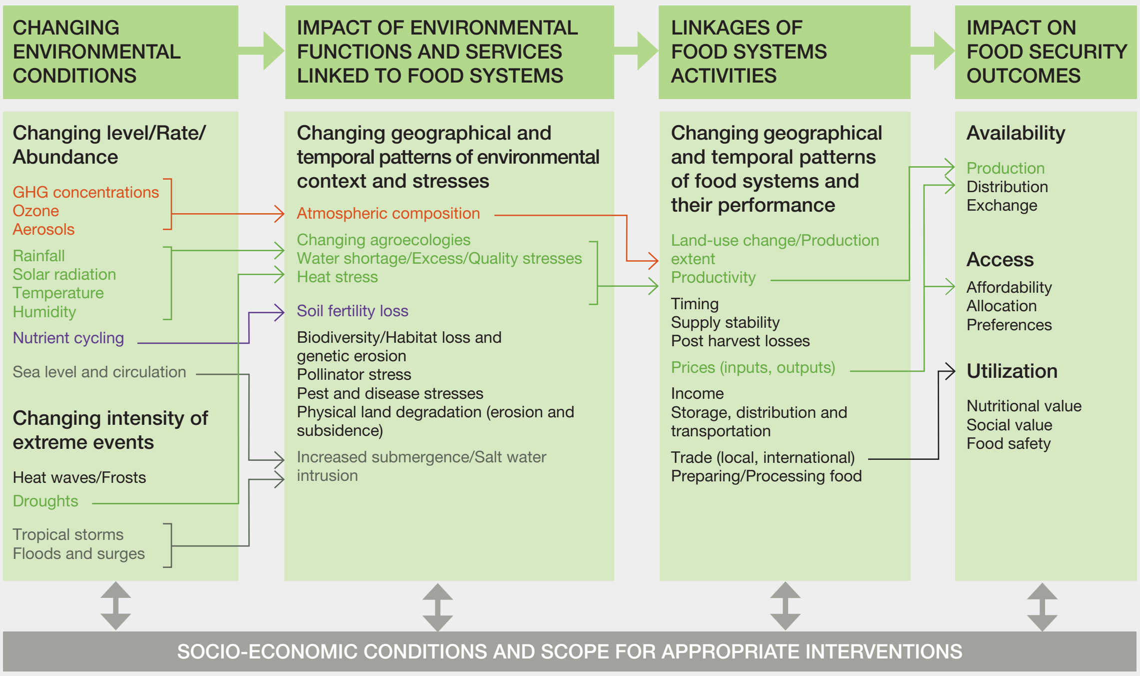


Figure 4 4 2 **Food Security impacts pathways in different global environmental assessment studies.**

Arrows indicate links in the analyses from environmental conditions (left) to food security outcomes (right).
Source: Wood *et al.* (2010).

system, in particular how natural and socioeconomic system components interact.

Water security

Regular access to clean water is a growing concern across multiple regions of the world, affecting two-thirds of the population (see 4.3.2.1). Water scarcity is strongly driven by behaviour driving overconsumption, infrastructure, and climate change. Climate projections indicate that a global temperature increase of 3-4°C could cause altered run-off patterns and glacial melt that will force an additional 1.8 billion people to live in a water scarce environment by 2080 (UNDP, 2007). Other drivers such as rising populations in flood-prone lands, climate change, deforestation, loss of wetlands and rising sea levels are expected to increase the number of people vulnerable to floods to 2 billion in 2050 (WWAP, 2012). Drylands are particularly vulnerable to changes in rainfall (Carpenter *et al.*, 2006), and with climate change, drought impacts are anticipated to intensify across increasing extents of the world's drylands (IPCC, 2013). The world's megacities are already facing increasingly frequent and acute water shortages, which can be expected to worsen in the future (Li et al 2015a). Similarly, in coastal regions, decreases in precipitation and fresh water supplies, along with projected increases in sea level, sea surface and air temperatures, and ocean acidification are projected to have major negative effects on water security for societies (McMillen *et al.*, 2014). The 'fresh water planetary boundary' is approaching rapidly (Dearing *et al.*, 2014; Rockström *et al.*, 2009), and sustainability of water use will likely be difficult to achieve in the near future (Gosling & Arnell, 2016). According to the results of the systematic literature review, water security indicators show negative trends in global and continental scale scenarios **(Figure 4.4.3)**.

Energy security

Ensuring the global population's access to modern and sustainable energy services in consideration of environmental integrity remains a major challenge for policymakers and practitioners worldwide. According to the systematic literature review, energy security derived from nature appears to be the only indicator with no identified negative trends in global scale scenarios **(Figure 4.4.3)**. However, scenarios such as decarbonisation ones, appear to also provide other benefits in addition such as lower energy market risks (Jewell *et al.*, 2014). However, energy security faces several other challenges. Energy security has both producer and consumer aspects (UNDP, 2004). Access to sustainable energy, which can include bioenergy sources, is critical in enabling people to meet essential needs linked with good quality of life as energy security encompasses availability, affordability, efficiency and environmental acceptability. The development of energy models in the 1970s in response to the energy crisis has provided relevant insights into the consumption and management patterns towards a sustainable energy for all future. On the other hand, current uneven global consumption coupled with the dearth of studies and quantitative data on energy use, especially from developing economies, presents a challenge for developing effective forecasting models. Scenarios based on non-linear energy consumption consider limiting overconsumption can keep 2040 energy consumption at 2010 levels, while increasing energy-for-life efficiency can keep 2040 energy use at 2010 levels (Pasten & Santamarina, 2012).

Livelihood and income security

While global scenarios lack sufficient attention to livelihood impacts, the results of the systematic literature review indicate regionally differentiated negative trends projected for livelihood and income security in the future **(Figure 4.4.3)**. Employment and incomes derived from nature are indicative for value derived in cash or direct use that impact good quality of life. Nature-based income, as part of environmental income, includes that derived from resources such as fish, timber, and non-timber forest products such as fuel wood, game, medicinals, fruits and other foods, and materials for handicrafts or art. It also includes income from nature-based tourism, as well as payments that rural landowners might receive for environmental services such as carbon storage or preservation of watershed functions. Also included is income from aquaculture as well as from small-scale agriculture, including commodity crops, home gardens, and large and small livestock. Nature-based livelihoods may become precarious with intensifying future trends in environmental change and its drivers (Hopping *et al.*, 2016). Climate change-induced depletion of household assets may have especially negative impacts on the future welfare of populations already fighting poverty. For example, farmers in Sub-Saharan Africa will spend an increasingly high share of their income on securing basic needs such as food, while housing and related needs also intensify (Enfors & Gordon, 2008).

Health

The future of biodiversity and ecosystem services is inextricably linked to that of human health and well-being, for instance, through supporting healthy diets to mitigating the health impacts of climate impacts or pollution. Many health benefits are related to the conservation or use of specific elements of biodiversity such as species or genetic resources. Indigenous communities increasingly anticipate, and are impacted by, changes to traditional practices and pathways of food, toxicity impacts from distant (e.g., pesticides) and local (e.g. mining) sources, hunting and gathering of medicinal plants, and experience their consequences for local diets and resistance to diseases, as exemplified in Queensland Australia (McIntyre-Tamwoy *et al.*, 2013), by Arctic Bay Inuit (Ford *et al.*, 2006), and across North American and Russian indigenous populations. As

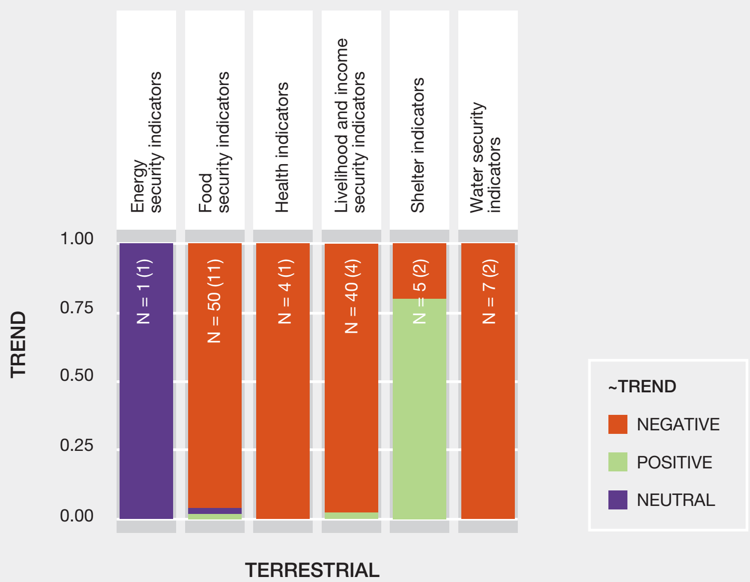


Figure 4 4 3 **Trends in selected indicators of GQL in terrestrial ecosystems. Colors indicate the value trend of the indicator.**

"N" indicates the number of results reported per facet, with the number of papers indicated in parentheses.

environmental hazards and extreme weather events increase in frequency, intensity or duration, they are expected to have increasingly visible consequences for health (Bai *et al.*, 2016).

Projected increases in the production of biofuel crops, in particular in case of woody bioenergy species (eucalypt, poplar) which emit more isoprene than traditional crops, suggest important impacts on ground-level ozone concentrations, and consequently on human health and mortality (Ashworth *et al.*, 2013). On the other hand, projected reductions of anthropogenic air pollutants point towards a widespread decline of small aerosol particles; projected future wildfires may not alter this general trend except for some parts of the wildfire season (Knorr *et al.*, 2017). Projected environmental changes are also expected to impact the prevalence of vector borne diseases such as malaria. Of the four MA scenarios, health under the "techno garden" scenario was expected to ameliorate due to technological advancements (Butler & Oluoch-Kosura, 2006; Carpenter *et al.*, 2006). Likewise, climate change under the five shared socio-economic pathways affects health outcomes (Ebi, 2014). Some health indicators can be expected to decline according to the systematic literature review **(Figure 4.4.3)**, however, more comprehensive global scenarios need to address various dimensions of health impacts.

4.4.1.1.2 Non-material dimensions of good quality of life

Along with material needs, human well-being depends profoundly on non-material and experiential factors (Butler & Oluoch-Kosura, 2006). However, narratives around good quality of life in global scenarios typically ignore such non-material dimensions which include but are not limited to: social relations, equity, cultural identity, values, security, recreation, knowledge and education, spirituality and religion, and freedom of choice and action.

Good social relations

Social relations refer to the degree of influence, respect, co-operation, and conflict that exists between individuals and groups (MA, 2005). Good social relations underlie the development of strong institutions and collective action, providing routes for sustainable use and management of nature and nature's contribution to people. The natural environment has important influences not only on individual well-being, but social relations as well (Hartig *et al.*, 2014). Good social relations also include mutual respect, social cohesion, and good gender and family relations. The linkages between good quality of life, nature and nature's contribution to people were explicitly identified in the Millennium Ecosystem Assessment, with an emphasis on cultural and spiritual values (MA, 2005). Even though the world is more connected than ever before, social differentiation remains a major constraint to social relations at multiple scales and in many cases is closely associated with inequality in access to nature and natural resources. Thus, it is crucial to address disparities among stakeholders in and across socio-ecological systems and the role of social relations in negotiating such disparities, in order to more fairly and equitably address how nature and NCP can be leveraged to promote a good quality of life. The degradation of ecosystems, highly valued for their aesthetic, recreational, or spiritual benefits, can also damage social relations, by introducing or exacerbating disparities among social groups and reducing the bonding value of shared experience, including resentment towards and resistance against groups that disproportionately profit from their damage. While global scenarios of future trends in social relations are elusive, climate and land-use changes in the future are highly likely to accentuate social inequity in use of and access to resources, in the absence of changes in governance arrangements to address current disparities.

Equity

Equity broadly concerns an even distribution of nature's contributions to people, and access to natural resources and rights (see also section 4.4.3). Typically three dimensions of equity are considered: (1) distribution, (2) procedure, and (3) context, access and power (McDermott *et al.*, 2013). Equity concerns evidence of parity in processes and outcomes across gender, age, race and ethnicity, income and other social indicators or axes of difference. It is fundamental to human rights, including the rights of IPLCs (see also **Box 4.4.1**), and implicitly influence nature, its contributions to people and good quality of life (Breslow *et al.*, 2016). Equity addresses fairness or justice in the way people are treated. In principle, equity concerns pertain to at least three domains –international, intra-country, and inter-generational. Social justice (equity) constitutes one of the three pillars of sustainable development, along with economic prosperity (development) and ecological integrity (sustainability) (Banuri *et al.*, 2001). Equity may increase in scenarios where the consumption of material goods is reduced relative to that of services and intangibles, such as the new welfare scenario (Sessa & Ricci, 2014). Equity is also expected to increase in global sustainable development scenarios such as SSP1, B1 (A1T), B2, sustainability first, global orchestration and techno garden, and some economic optimism scenarios such as SSP5. In regional competition scenarios such as SSP3/4, A2, security first and order from strength, equity is expected to be low (see section 4.1).

Cultural identity

Cultural identity includes concerns related to the terms, language, activities and practices that embody the relationships of people and nature. The cultural identity of IPLCs is particularly linked to long-term material and non-material relationships to nature and place, with direct and sustained physical and experiential interactions (e.g., see section 4.3.2.3 above). As indicated earlier, among the direct and indirect drivers of changes to such interactions, and to fundamental aspects of IPLCs cultural identity, are urbanization, climate change, demographic changes, technology, psycho-social or cultural factors, and health and development. Future threats to biodiversity and ecosystem services also constitute imminent challenges to the cultural identity of communities, particularly when faced with environmental degradation. For example, "blue-ice," as a term inherent to First Nation languages and as the material formation on lakes and rivers, links transportation to access to food and energy. It is thus central to First Nations' cultural identity and traditional activities, and their future well-being (Golden *et al.*, 2015). Such relations are at once material and symbolic. As section 4.3.2.3 also highlights, symbolic meaning is intimately tied to spiritual, religious and cultural identity, and strongly shapes social cohesion, and future trends in these relations are central to IPLC futures.

Personal and physical security

Future climate change poses physical risks with implications for human safety and security. Such risks emanate from multiple dimensions, including those linked to increased exposure to episodic stress (e.g., extreme climate events) as well as chronic pressures (e.g. related to warming temperatures and sea level change). For instance, climate change scenarios in the Great Barrier Reef indicate marked declines in security that accompany declines in ecosystem services, along with indicators of equity, education, health and shelter (Bohensky *et al.*, 2011a). In other examples, projections of future population dynamics have indicated that more people may live in areas that are prone to both floods and wildfires in the future (Knorr *et al.*, 2016). In northern regions, among other risks, for some populations, traveling on thinning ice in winter is becoming more dangerous, restricting movement of people and goods (Ford *et al.*, 2006).

Recreation and leisure

There is considerable research from environmental psychology on the human health and well-being benefits from recreation in nature (Barton & Pretty, 2010; Marselle *et al.*, 2014). The Millennium Assessment Technogarden scenario (see section 4.1) argues for the multifunctionality of land-use including recreational opportunities, seen as an affordable luxury in e.g., the Order from Strength scenario (MA, 2005; see also Appendix 4.4). Similarly, the SRES B1 (A1T) mentions the preservation of recreational spaces (Nakicenovic *et al.*, 2000; see also Appendix 4.4). Loss of coral reefs under the RCP2.6 and RCP8.5 scenarios (section 4.2.2.2.2) could cost between U.S. $1.9 billion and U.S. $12 billion in lost tourism revenues per year, respectively (Gattuso *et al.*, 2015). The loss of recreational areas such as camping sites is signaled as a regional concern by indigenous participants in case studies in Australia (McIntyre-Tamwoy *et al.*, 2013).

Knowledge and Education

Knowledge and education related to biodiversity and ecosystem services are essential for ensuring good quality of life. The taxonomic records of world fauna and flora indicate 8.7 million known species (Mora *et al.*, 2011), which represent only a fraction of the species that may exist (WRI *et al.*, 1992), indicating a large knowledge gap on fundamental aspects of biodiversity. It has been estimated that 86% of existing species on Earth and 91% of species in the ocean still await description (Mora *et al.*, 2011). Much of the knowledge used in scenarios of biodiversity and ecosystem services is derived from biology, ecology and related disciplines.

Yet, a variety of conceptualizations of biodiversity are embedded in local knowledge and cultural memories directly relevant to regional and global resource and food production systems (Nazarea, 2006), but poorly represented in future scenarios. Additional perspectives could be derived from work on human cognition, decision-making, and behavior. For example, ethnobiology of agricultural diversity, cultural ecology of plant genetic resources, participatory conservation, politics of genetic resources, and legal dimensions of biodiversity conservation are very poorly represented in scenario development. The role of education has been to some extent explored in global scenarios. Specifically, the narratives of scenarios SSP1 and SSP5 assume that the human capital component of education is highest compared to SSP2, SSP3 and SSP4 (KC & Lutz, 2017). Schools play an important role in educating pupils and students to be active and responsible towards the environment, and the challenge of biodiversity conservation (Torkar, 2016; Ulbrich *et al.*, 2010).

Spirituality, religion

A number of studies highlight the ways in which spirituality is related to good quality of life. Spirituality has been considered in a variety of ways, ranging from the traditional understandings of spirituality as an expression of religiosity in search of the sacred, to humanistic views of spirituality not specifically anchored in religion, or at least, ecclesiastical religion. Fisher (2011) noted that the spiritual health of individuals has four important domains: personal, communal, environmental and transcendental. Many religions emphasize a deep connection or oneness with nature, including Hinduism, Buddhism, Jainism, Christianity and Islam. For example, in India, patches of forest frequently constitute sacred groves of varying sizes, which are communally protected with significant spiritual connotations.

The rapid retreat of the Gangotri Glacier, the sacred source of the Ganges, is alarming for Hindu religious practitioners (Verschuuren *et al.*, 2010). The landscape that surrounds sacred groves has a vital influence on biodiversity within them (Bhagwat *et al.*, 2005). Similarly, sacred sites in Italy often display ecological features that highlight their important conservation role (Frascaroli, 2013). These sacred places are, symbolically, repositories of knowledge of our planet as 'home.' Our relationship with nature and GQL, where the spirit of nature and culture meet, and are additionally memorialized and maintained by rituals and festivities performed there. However, most of the current archetype scenarios of biodiversity and ecosystem services fail to incorporate the spiritual and cultural significance of nature.

Freedom of choice and action

Freedom emphasizes a person's social, political, economic, and personal rights, and whether one is actually able to exercise these rights. Freedom of choice and action is a vital pre-requisite to GQL. In practical terms, freedom can promote or inhibit access to nature and its multiple benefits needed to sustain life. Human and natural constraints prevent different groups of people around the world from having or exercising freedom of choice and action to access nature and its benefits needed for good quality of life. Thus, even though nature and its contributions to good quality of life may be abundant in certain areas, lack of freedom may impede access. Projected changes to climate, biodiversity and ecosystem services can be expected to directly impact social access to nature and its benefits. In addition, future changes can strongly impact the institutions shaping freedom and choice. For instance, experience has shown that sociopolitical institutions and environmental regulatory regimes tend to favour certain groups over others. In the Doñana protected area from Southern Spain, freedom of action and choice is completely reduced in a future scenario of market liberalization (Palomo *et al.*, 2011). Similar trade-offs with GQL are evident in the varying degrees of environmental protections at the global scale. For instance, different IUCN categories in protected areas, from the most stringent preservationist approaches excluding human use, to the more integrated protection categories incorporating some (sustainable) use, have vastly different implications for GQL in different communities living in those regions.

4.4.1.2 Good quality of life across worldviews and knowledge systems

GQL conceptualizations across worldviews and knowledge systems vary considerably due in part to values, beliefs and worldviews, as well as social and political contexts. What GQL entails is highly dependent on place, time and culture, with different societies espousing different views of their relationships with nature and placing varying emphasis on collective versus individual rights, or the material versus the spiritual domain. Understanding and appreciating plausible GQL scenarios require an integrative assessment of subjective and objective approaches and indicators for quality of life, including quantitative or qualitative social and economic measures (Cummins *et al.*, 2003; Diener *et al.*, 1999; Easterlin, 2003; Haas, 1999). Over the past half century, increasing research and policy attention has been directed to socio-ecological concerns relevant to Indigenous People and Local Communities (IPLCs) (e.g., **Box 4.4.1**), with recognition of long histories and ongoing processes of exclusion and marginalization of IPLCs in ecosystem and biodiversity conservation and management across socio-ecological regions. The IPBES framework acknowledges the varying perspectives of GQL across knowledge systems, cultures and societies (Díaz *et al.*, 2015).

While indigenous worldviews differ from one community to another, indigenous understandings of well-being are also frequently intertwined with understandings of nature; the relationship between people and their environment happens not only at a cognitive level. In many societies, "prestige and satisfaction are gained through relationships and generosity rather than in accumulation of personal wealth. A good life is one spent in service to one's community, in living in balance with the other lifeforms of one's homeplace. Responsibilities extend not just to the present, but to many generations into the future" (Turner & Clifton, 2009). Different understandings also exist around the notion of 'time'. In Iñupiaq and Siberian Yupik culture, for instance, it is important for hunters to avoid speculating about the future, reflecting the belief that one should be humble about one's abilities to predict it, and not expect any one particular outcome over another (Voorhees *et al.*, 2014). Addressing quality of life under different plausible futures will benefit from bridging indigenous and local epistemologies with scientific knowledge systems (Tengö *et al.*, 2017), such as initiatives addressing mitigation and adaptation from a local perspective (UNU-IAS & IGES, 2015).

4.4.2 Linking good quality of life to nature and nature's contributions to people across future scenarios

4.4.2.1 Mediating factors of future GQL and NCP

Future quality of life and its relation to nature and its contributions to Ppeople (NCP) is expected to be mediated by a bundle of overlapping factors across socio-ecological systems at local and global levels, from the individual or the household to the system **(Figure 4.4 4)**. These mediating factors are fundamental to shaping the productive base of a society, including substitutable capital assets, i.e. natural,

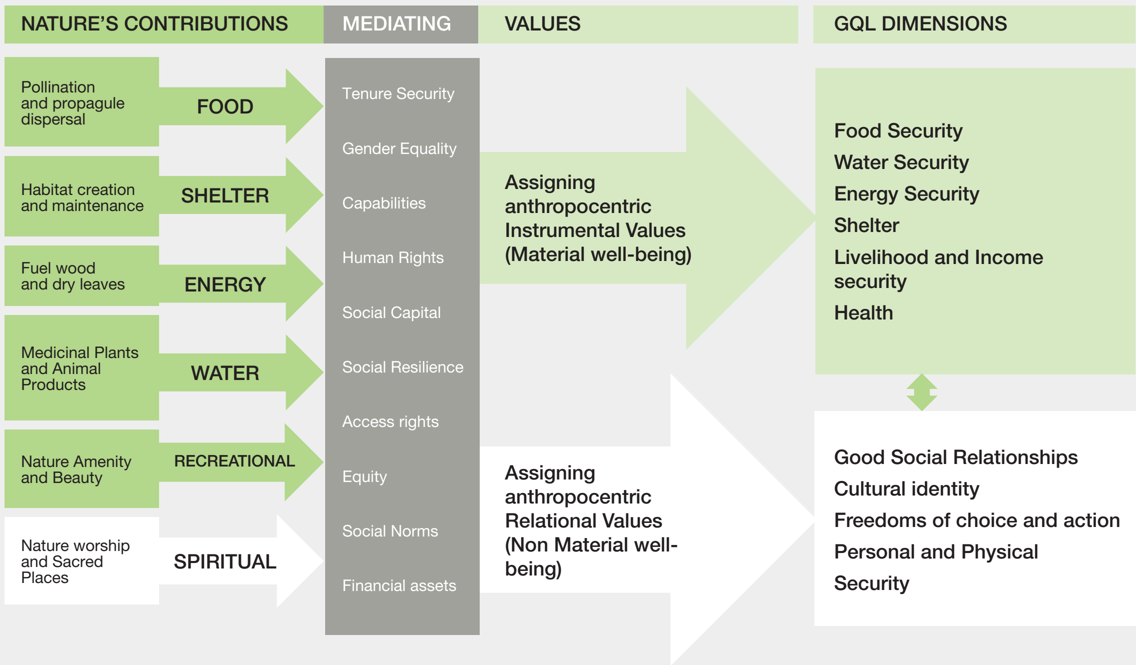


Figure 4 4 4 **Conceptual model of mediated relationships between nature's contributions to people and good quality of life (GQL).**

produced, and human capital (Duraiappah *et al.*, 2014). They are akin to indirect drivers of changes to nature, NCP and GQL, and include tenure security (e.g., use and access rights), equity concerns, power relations, formal and informal institutions and human rights, technology access, financial assets, and social capital and social resilience (Horcea-Milcu, 2015; Shapiro & Báldi, 2014; Spangenberg *et al.*, 2014). However, inequities, political challenges and distributional issues are seldom discussed by scenarios considering implications for GQL.

Social groups have distinct ways to derive well-being from NCP, as a result of a range of interlinked mediating factors (Horcea-Milcu, 2015). For example, policies such as the European Common Agriculture Policy rural development program of agri-environment schemes may increase nature's contributions to people, but because it does not holistically engage with mediating factors it will not equitably increase access to benefits (Horcea-Milcu, 2015). Although people's values and attitudes are crucial in shaping the future, they are rarely central to scenario exercises. Novel methods, such as the three horizons approach (Sharpe *et al.*, 2016) have been developed to fully integrate people's worldviews into scenario planning, however transcendental values held by the social groups are only beginning to be considered (Kass *et al.*, 2011). For example, the ethnographic futures framework focuses on how changes in the natural environment take place through human agency and how society will act as recipient in the future (Kass *et al.*, 2011). Importantly, the process of elaborating scenarios is increasingly taking into account participatory approaches and corresponding value negotiations around the meaning of good quality of life. Consequently, ethical questions emerge regarding how to build scenarios so that local knowledge and IPLCs are not coopted in ways that may exacerbate processes of their social marginalization (but see also **Box 4.4.1**).

How mediating factors may be expected to change in magnitude and direction across different archetype scenarios remains to be explored. Scenarios of regional sustainability seem more suited for mitigating the negative influence of mediating factors (Hanspach *et al.*, 2014). Mismatches among mediating factors, nature and NCP may pose challenges. For instance, Duraiappah *et al.* (2014) identified mismatches of individuals' values (e.g., of ecosystem services within different social contexts), mis-matches in ecosystem services and ecosystem scales (at which levels of biodiversity, ecosystem processes and functions operate to produce the bundle of provisioning, regulating, and cultural services), and mis-matches of institutions (those that account for spatial, temporal, and functional fit in managing ecosystem services).

The way NCP components will be filtered and transformed to GQL components and reach beneficiaries such as individual, social groups or societies will be highly influenced by mediating factors such as: access arrangements, assets, institutions, values and norms. One avenue to incorporate this variability is integrating more participatory, deliberative or transdisciplinary processes into scenario building endeavors towards improved considerations of GQL in its variety of components, whether material or non-material, of local or global concerns. Storylines of socio-economic development used in global scenarios include few indicators of GQL, typically predicated on its material aspects. Given these limitations, lessons learnt from the current assessment is that indicators of GQL in global scenarios generally improve in the future in the “global sustainability”, “regional sustainability”, and “economic optimism” scenario archetypes. However, continued degradation of nature and non-provisioning NCP in the “Economic optimism” scenarios suggests that the decoupling of GQL from Nature and non-provisioning NCP that is often currently observed could potentially continue into the future. Indicators of GQL have the poorest future trajectories in the “regional competition” scenarios and do only slightly better in “business-as-usual” scenarios at the global scale.

4.4.2.2 Future scenarios of GQL and NCP

Key characteristics of GQL indicators are assumed to substantially improve in the future with a reduction in global poverty in the “global sustainability” archetype and to a lesser extent in the “regional sustainability,” but with recognizable regional differentiation (section 4.1). These improvements in GQL in sustainability scenarios go hand-in-hand with the most favorable projections of future dynamics of nature and NCP. However, continued degradation of nature, especially in developing economies of the tropics, and the consequences on NCP in the “economic optimism” scenarios suggest that the decoupling of economic growth on the one hand and nature, NCP and GQL on the other hand (see Chapters 2 & 3, and sections 4.2.2-4.2.4) could potentially continue into the future.

Indicators of GQL (Table A4.4.1, Appendix 4.4) have the poorest future trajectories in the “regional competition” scenarios and do only slightly better in “business-as-usual” and “economic optimism” scenarios at the global scale with substantial geographical differentiation. One of the underlying components of these storylines (particularly in the regional competition archetypes) is fragmentation, and large geographical variation in indicators of GQL. These scenarios also lead to the least optimistic future projections of nature and NCP (sections 4.2 & 4.3). These scenarios suggest that many of the current trends in socio-economic development (see Chapters 2 & 3) are projected to lead to lose-lose-lose responses of nature, NCP and GQL in the future (section 4.5) with inhabitants of developing economies expected to be severely impacted.

The literature review also finds that plausible scenarios are more likely to recognize the importance of nature for fulfilling material dimensions rather than the non-material ones. Similarly, there is a gap in the literature on the extent to which GQL dimensions depend on nature’s contributions, and how they fit together. The literature clearly documents a strong correlation between nature’s contributions and good quality of life (**Figure 4.5.2b** in section 4.5). Notably, positive trends in NCP are correlated with corresponding positive trends on GQL (top right of **Figure 4.5.2b**). Negative trends in NCP and GQL are similarly correlated (bottom left of **Figure 4.5.2b**) and comprise the bulk of the correlations reported as scenarios’ outcomes. Nevertheless, analyses of such NCP-GQL relations could be further specified for scenarios exploring how those relations are mediated by contextual factors. For instance, future scenarios voiced by Amazonian communities reveal concerns with regard to livelihoods, equity aspects and the long-term impacts for communities and nature (Evans & Cole, 2014).

A challenge to the assessment of NCP and GQL under different future scenarios is their socially differentiated nature. This means that different groups may experience changes in NCP differently and with distinct impacts on GQL, so that a given change scenario usually implies winners and losers. People vary in their access to ecosystem services, exposure to disservices, dependence on ecosystems, and needs and aspirations for NCP. These are influenced by societal structures and norms as individual characteristics (Daw *et al.*, 2011) and power relations (Berbés-Blázquez *et al.*, 2017; Horcea-Milcu, 2015). Access shapes the transformation of ecosystem services to human well-being. For example, the perception of, dependence on and access to ecosystem services are strongly gendered. Men and women participate in different ecosystem-based livelihoods due to gendered roles and responsibilities gendered access to physical space, and gendered knowledge systems about ecosystems and NCP.

Thus, decision-making about environmental management with implications for different bundles of ecosystem services is an intently political process, with different stakeholders favouring different outcomes and holding different levels of power within those processes (Schoon *et al.*, 2015). Value systems and societal preferences for example evolve through globalisation of culture, or from burgeoning environmental consciousness in society (Everard *et al.*, 2016). Thus, changes in NCP and GQL are affected by social, economic, institutional change as well as biophysical change. Also how GQL of particular groups of people will respond to changes in biophysical conditions will be influenced by a wide range of factors (Daw *et al.*, 2016); see also section 4.4.2).

Evaluating GQL under different scenarios of change can benefit from deliberative and participatory approaches that consider a wide range of stakeholder views, and disciplinary perspectives (e.g., Brand *et al.*, 2013). Such a diversity of perspectives is necessary to take account of the multiple interacting factors and socially differentiated experiences, vulnerabilities and preferences for NCP (Barnaud *et al.*, 2018) as well as complexity and uncertainties in how NCPs evolve (Lele & Srinivasan, 2013).

Narrowly informed assessments of change may overlook socially differentiated outcomes. For example, aggregate analysis of a small-scale fishery in Kenya showed a win-win opportunity to improve profitability and conservation outcomes by reducing fishing effort and the use of small meshed beach seine nets. However, an inclusive participatory modelling approach showed that the livelihoods of certain groups, such as women traders would be negatively impacted by such a change due to the gendered nature of the value chain (Daw *et al.*, 2015). Likewise, in southern India, a disaggregated economic analysis shows how different stakeholder groups would experience different benefits and costs from the implementation of a forest conservation area (Lele & Srinivasan, 2013). For example, non-indigenous groups would suffer from curtailment of firewood and grazing benefits while indigenous groups would also lose out on these services but benefit to a greater extent from increased opportunities and sale of non-timber forest products. Importantly, from the perspective of developing scenarios, these wins and losses are shown to be highly contingent on complex institutional, technical and ecological dynamics in terms of access arrangements, irrigation methods and invasive species, respectively (Lele & Srinivasan, 2013).

Trade-offs between the good qualities of life of particular societal groups might easily be overlooked due to the complexity of ecological and social relationships, because the 'losers' of such trade-offs are marginalised or lack a voice in assessment processes and because of the psychological and political biases towards 'win-win' narratives that overlook uncomfortable or inconvenient trade offs (Daw *et al.*, 2015). A limitation with participatory approaches is the difficulty of imagining future scenarios of changes in the 'demand side' of NCP. So, a group may discuss how changes in a resource might be affected by climate change, but it is often framed in terms of current social conditions. Social, economic and political changes can have major impacts on NCP and subsequent effects on GQL.

Perspectives on GQL are also disputed and dynamic amongst modern and urban populations in wealthy countries. Increasing interest in well-being by Western governments (e.g., the OECD better life index http://www.oecdbetterlifeindex.org/) is critical for future scenarios because development trajectories, informed by the pursuit of economic growth are a major driver of ecosystem change. The possibility of a broader conceptualisation of well-being informing economic and development policy could have a major impact on the drivers behind environmental change.

Different conceptualisations or subjective experiences of GQL extend into relationships with ecosystems. While dominant economic framings in modern societies have emphasised instrumental values of nature, spiritual and aesthetic-cultural

Box 4 4 1 Climate Futures and Rural Livelihood Adaptation in Nusa Tenggara Barat, Indonesia.

What different futures are plausible for Indigenous People and Local Communities (IPLCs)?

Nusa Tenggara Barat (NTB) Province in the island archipelago of Eastern Indonesia is one of the country's poorest regions, and highly vulnerable to climate change due to dependence on rural, ecosystem-based livelihoods (Kirono *et al.*, 2016). It is therefore representative of other island regions in the tropical Asia-Pacific, which share the challenges associated with rapid change and entrenched poverty intertwined with complex traditional culture (Butler *et al.*, 2014, 2016a).

To assist communities to navigate future changes, from 2010-14, the Australian Government funded a series of scenario planning workshops with multiple stakeholders to investigate alternative development pathways and potential impacts on ecosystem services (Butler *et al.*, 2015). The project's Theory of Change assumed three evolutionary stages of adaptive co-management that would be triggered: 1) capacity building, 2) policy and program development and 3) implementation, adoption and scaling out. A participatory evaluation was carried out to test these assumptions and measure outcomes (Butler *et al.*, 2016c).

A key principle of the scenario planning process is that multiple stakeholders must be engaged through collaborative learning and knowledge co-production (Butler *et al.*, 2016c). Scientific and local knowledge was integrated in an interactive and iterative process throughout the workshops with the goal of co-producing knowledge via a 'learning spiral' **(Figure 4.4.5)**. Stage 1 scenario workshops were carried out with provincial level stakeholders, and then repeated in Stage 2 for five sub-districts and their community level stakeholders; Stage 3 then integrated the outputs of Stages 1 and 2 **(Figure 4.4.5)**. Stages 1 and 2 were structured around four questions: 1) What are the drivers of change for livelihoods? 2) What is the desired future for livelihoods? 3) What are the possible futures for livelihoods? and 4) What are the priority 'no regrets' adaptation strategies required to achieve the desired future in spite of future uncertainty?

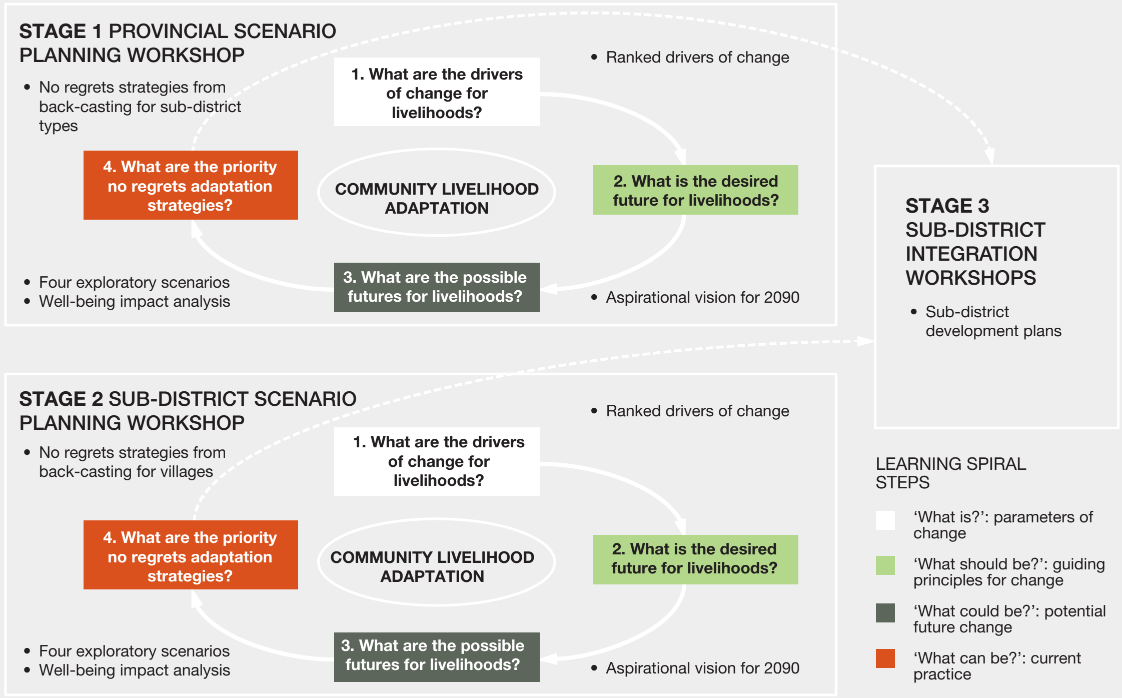


Figure 4 4 5 **Stage 1 and 2 scenario planning workshop steps and primary outputs (bullets) based on Brown's (2008) learning spiral.**

Also shown are the links to the subsequent Stage 3 sub-district integration workshops. From Butler *et al.* (2016b).

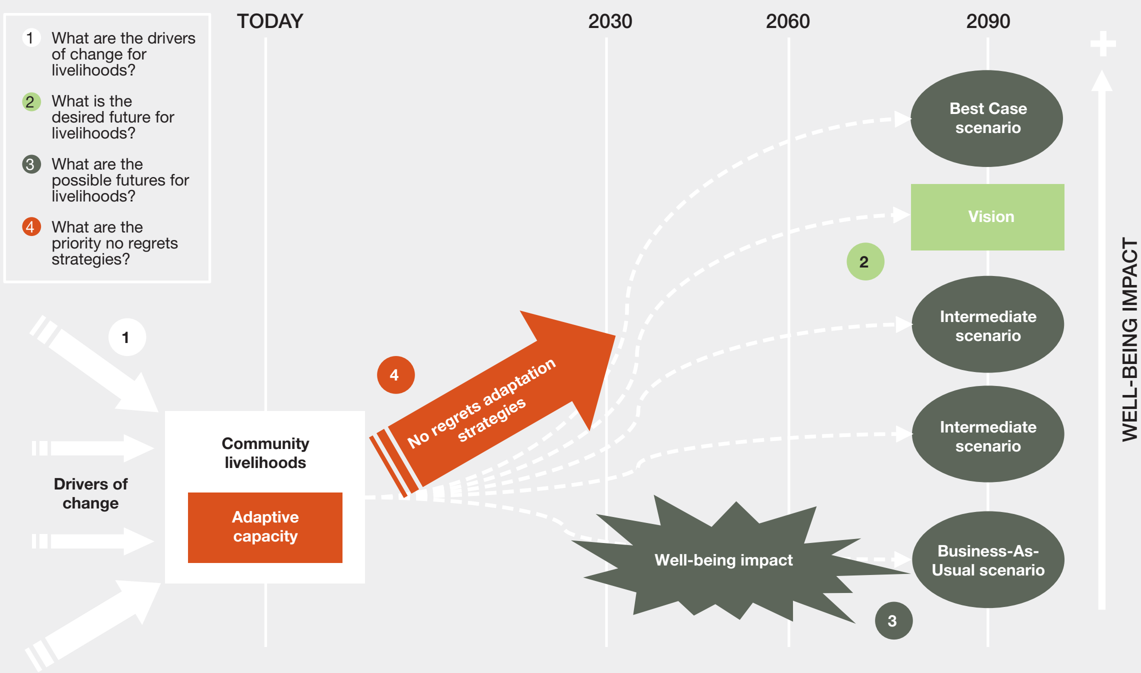


Figure 4 4 6 **The 'roadmap' used in the Stage 1 and 2 scenario planning workshops to explain the sequential learning steps.**

The step numbers and questions correspond to the learning spiral in Figure 4.4.5. From Butler *et al.* (2016b).

Participants in Stage 1 identified two key drivers from a list of 50 current drivers of change: development of human resources and climate change. They described a desired future vision for NTB rural livelihoods in 2090 based on adequate income, health, food security, social cohesion and freedom of choice for a good life. A matrix of four possible future scenarios was created from better or worse extremes of human resources development and climate change. Participants created narratives and illustrations for each scenario **(Figure 4.4.7)**.

An ecosystem goods and services typology and model was used to project future ecosystem goods and services and impacts on human well-being in 2030 for the business-as-usual scenario **(Figure 4.4.6)**. The most affected ecosystem types were rice and bandeng (fish) ponds, diverse cropping and coastal activity, diverse agriculture and forest use, and rice and tobacco (Skewes *et al.*, 2016). However, communities dependent on these ecosystem types for their livelihoods have varying levels of adaptive capacity. Hence, an adaptive capacity index was developed to rank vulnerability of NTB livelihoods, which identified the diverse cropping and coastal activity livelihood as most vulnerable. This assessment helped the participants to select sub-districts for community case studies in the next phase. Based on ecosystem goods and services and human well-being impacts and adaptive capacity for each typology, participants designed adaptation strategies for livelihoods to steer them away from 'business-as-usual' towards the NTB vision and the 'Best Case' Well-being Village scenario.

The same process was undertaken for each case study sub-district in the Stage 2 workshops, with more focus on local issues, knowledge and ecosystem goods and services.

Through the process, surveys identified distinct 'knowledge cultures' amongst stakeholder types in this region (e.g. government, communities and NGOs), with differing perceptions of future time horizons, climate change and development priorities (Bohensky *et al.*, 2016; Butler *et al.*, 2015). This finding justified the project design, which intentionally carried out the process at multiple scales in Stages 1 and 2, and then finally integrated the results by bringing stakeholders representing different scales together in Stage 3 (Figure 4.4.5). As a consequence, learning and innovation was one of the primary outcomes of the process (Butler *et al.*, 2016c).

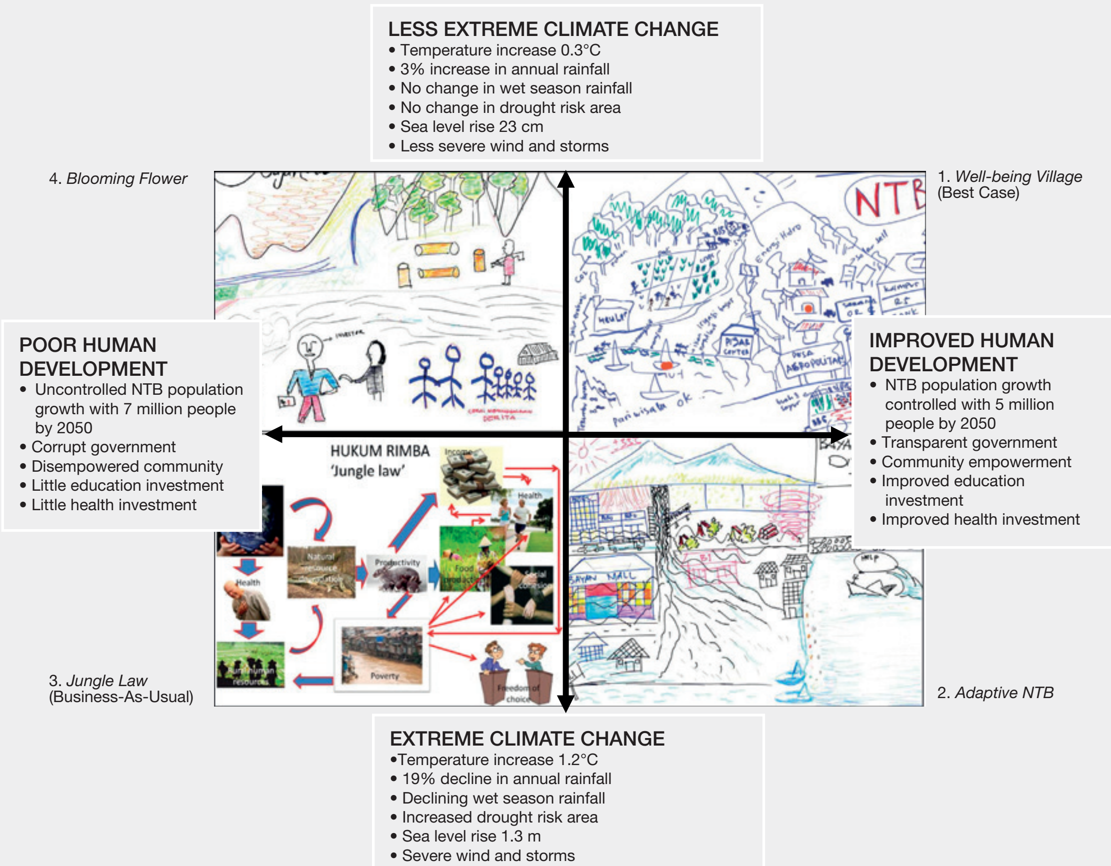


Figure 4 4 7 **Driver themes, sub-themes and exploratory scenarios for 2090 from the Stage 1 provincial workshop.**

From Butler *et al.* (2016b).

How indigenous and local knowledge (ILK) can be integrated with scientific knowledge in scenario-based projects towards Sustainable Development Goals (SDGs)

Participatory scenario planning has become a popular tool for navigating changes faced by many Indigenous Peoples and Local Communities. Integrating knowledge and multiple perspectives on change drivers, how the future might look and how stakeholders might respond, can potentially catalyse single-, double- and triple-loop learning that enable adaptation (Butler *et al.*, 2016c; Totin *et al.*, 2018).

The power of scenario planning to effect real change may be limited, however. While such scenarios present local visions for alternative futures in ways that conventional models, projections and forecasts cannot (Peterson *et al.*, 2003; Wollenberg *et al.*, 2000), their widespread adoption has not been matched by adequate resources. A review of place-based participatory scenarios found that very few projects complete a rigorous evaluation of outcomes (Oteros-Rozas *et al.*, 2015). Even in well-funded, multi-year projects such as the project in NTB, scenarios have only catalysed partial learning and change (Butler *et al.*, 2016a). In particular, the adoption of incremental rather than transformative adaptation strategies suggest that root causes of community vulnerability were not fully acknowledged, although numerous systemic drivers were identified. Scenario planning should be considered as only one tool in a process of capacity-building. This is particularly important in developing country contexts where capacity of stakeholders is low (Chaudhury *et al.*, 2013; Vervoort *et al.*, 2014). One-off scenario planning can generate enhanced learning and social networks but is unlikely to create transformational change needed to address systemic issues such as politics and institutions (Totin *et al.*, 2018). Ideally, the principles of futures analysis and learning should also be integrated within existing decision-making or development planning processes (Butler *et al.*, 2016c). If sustained, such grassroots platforms may catalyse and implement transformation, and ultimately enable vulnerable communities to leap-frog the SDGs (Butler *et al.*, 2016b).

values, whether of indigenous or modern societies, are hard to capture by instrumental thinking that underlies economic ecosystem service approaches. Instead, they are grounded in conceptions of nature that differ from the ecosystem services conceptual framework (Cooper *et al.*, 2016).

4.5 TRADE-OFFS, CO-BENEFITS AND FEEDBACKS BETWEEN NATURE, NATURE'S CONTRIBUTIONS TO PEOPLE AND GOOD QUALITY OF LIFE

4.5.1 Analysis of interactions from the Systematic Literature Review

Very few models and scenarios have been developed that simulate the complex interactions between nature, nature's contributions to people and good quality of life at continental or global scales, although such interactions are qualitatively well described and documented in the literature. As a result, scenario outcomes developed so far do not cover the full range of plausible futures. In the systematic literature review conducted for this chapter (Appendix A4.1.1), only 14 papers (out of a total of 572 papers), reporting a total of 41 different scenarios outcomes, addressed interactions between nature and NCP and GQL **(Figure 4.5.1)**. Advancing scientific knowledge about such interactions is crucial because of their relevance for identifying feedback effects, understanding trade-offs or win-win solutions and the risk of breaching thresholds and so–called "tipping points".

Analyses of the systematic literature review **(Figure 4.5.2)** suggest further that while relationships between nature, NCP and GQL are both positive and negative, the reported results indicate that the majority of indicators' trends are correlated either positive-positive or negative-negative. For instance, if a trend in a nature indicator is positive, there is more chance that a trend in an associated NCP is also positive **(Figure 4.5.2a)**, and conversely for negative/negative relationships. 62% of the simulated interactions between nature and NCP indicators' trends are correlated that way (excluding cases where both indicators of Nature and NCP have null trends). Likewise, the majority of relationships between NCP and GQL are positive-positive or negative-negative (80%; **Figure 4.5.2b**). The high proportion of such correlations suggests the existence of opportunities and potential co-benefits of measures aimed at preserving a specific nature's component, or a specific ecosystem service (section 4.5.3). However, the literature analysis does not allow to decipher whether there are causal relationships behind the positive correlations, and whether there are differences across regions or changes in trend over time (near vs. longer-term future). In addition, the level

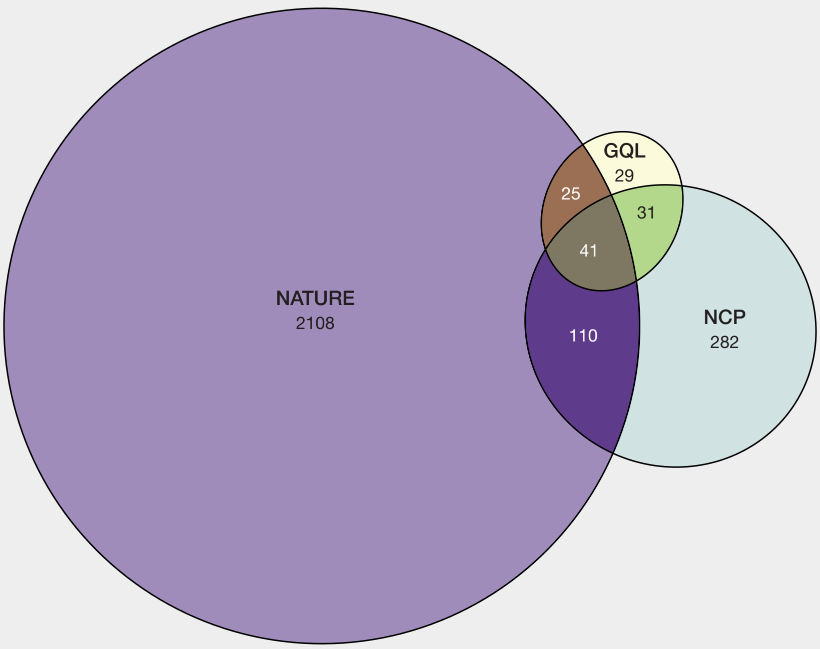


Figure 4 5 1 **Number of results in the systematic literature review (for details, see Appendix A4.1.1) which report projections of at least one indicator of nature, nature's contributions to people (NCP), or good quality of life (GQL).**

Overlaps of the circles indicate that a result contained trends for more than one group of indicators.

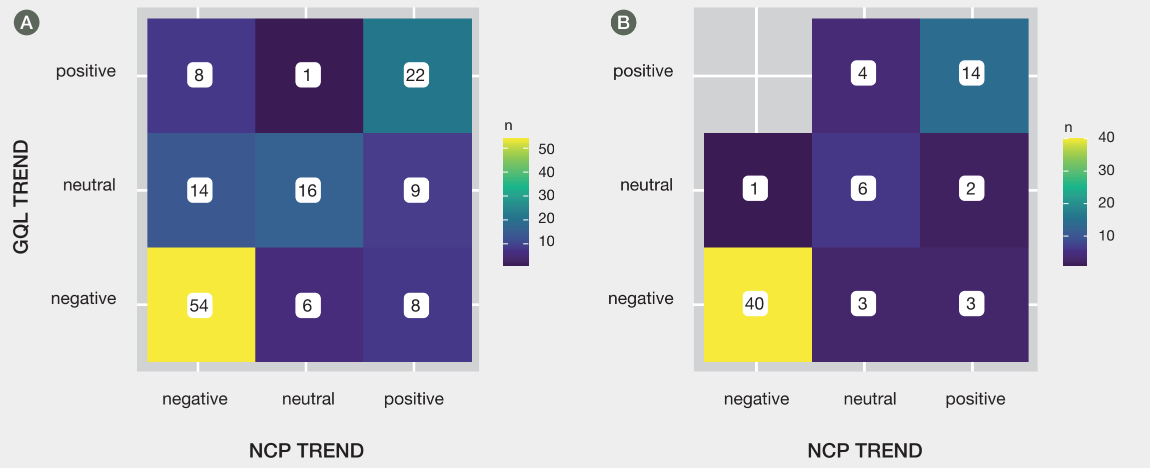


Figure 4 5 2 **Heatmap showing the relationship between negative, neutral and positive trends reported for indicators of nature and nature's contributions to people (NCP, left panel, A), and NCP and good quality of life (GQL, right panel, B) in output of the models and global scale scenarios from the systematic literature review (Appendix A.4.1). n: number of results reported (i.e. multiple results per paper possible).**

of correlation is neither quantified, nor linked to any potential feedback effects that can dampen or amplify the drivers impacts on nature, NCP and GQL (section 4.5.1). There are a few numbers of negative correlations between nature, NCP and GQL indicator trends, which, although found in a lower proportion, can represent difficult trade-offs between different policy targets, e.g. between conservation and food provisioning targets (section 4.5.2).

4.5.2 Feedbacks

Feedbacks are processes that either reinforce or degrade the resilience of a stable state (Briske *et al.*, 2006), with both damping (also known as negative or balancing) and amplifying (also known as positive or reinforcing) feedbacks acting together or separately in a complex system to hold it in a particular state. A compilation of studies illustrative for feedbacks can be found in the Appendix (Table A4.5.2).

Feedbacks are well documented in the climate system (Ciais *et al.*, 2013). For example, increases in atmospheric concentration of CO_2, warmer temperatures and/or altered precipitation impact uptake and release of CO_2 in vegetation and soils, which in turn amplifies or dampens the original forcing via feedbacks on atmospheric CO2. Along coastlines, global sea level rise, temperature extremes and storm surges are projected to damage marine vegetated habitats and decrease wetlands area (Crosby *et al.*, 2016; Hoegh-Guldberg *et al.*, 2018), with potential negative feedbacks on climate change as these areas play key role in carbon burial and sequestration (Duarte *et al.*, 2013; section 4.2.2.2.2). In terrestrial systems, shifts in vegetation cover associated with climate change and atmospheric CO_2 (such as changes in woody type and cover, reduction of permafrost and peatlands, or shifts in fire regimes) play additional important roles in these dynamics (see section 4.2.4.1; Achard *et al.*, 2014; Arneth *et al.*, 2010; Davidson *et al.*, 2012; Lenton *et al.*, 2008; Lenton & Williams, 2013; Pearson *et al.*, 2017; Stocker *et al.*, 2013). In addition, reduced evapotranspiration due to climate change (or deforestation) feeds back on surface humidity, formation of regional cloud or rainfall which could also enhance forest vulnerability to fire and drought (Avissar & Werth, 2005; Devaraju *et al.*, 2015; Lenton & Williams, 2013; Quesada *et al.*, 2017b; Ray *et al.*, 2006). However, there remain large uncertainties in the magnitude and direction of feedbacks (Arneth *et al.*, 2010; Friedlingstein *et al.*, 2014; Raes *et al.*, 2010; Roy *et al.*, 2011; Stocker *et al.*, 2013).

Feedbacks also exist in coupled socio-ecological systems (and hence between nature, NCP and GQL; Hersperger *et al.*, 2011; Hull *et al.*, 2015; Robinson *et al.*, 2017). For instance, infrastructure used for extraction and use of natural resources generates wealth, which amplifies technological development and further extraction of resources. As the demand of a natural resource intensifies, its economic value increases. To seek monetary profits, exploitation increases as well and as long as the demand is high, economic value and exploitation continue to increase (Cinner *et al.*, 2011; Leadley *et al.*, 2010, 2014; Walker *et al.*, 2009. A social driver like market demand increases the value of natural resources with increasing scarcity of the resource. This negative feedback starts to be accounted for in fishing scenarios, with for example, high short-term economic incentives to exceed sustainable exploitation targets of marine resources, potentially leading to increases in fishing capacity and rapid depletion of fish stocks (Merino *et al.*, 2012). This often happens with large predatory fishes that are of high monetary value (Tsikliras & Polymeros, 2014). Overfishing leads to their depletion, new global markets develop for alternative species in turn (Quaas *et al.*, 2016), often their own prey, which leads to further depletion of marine resources (Steneck *et al.*, 2011). In addition, economic market feedbacks in response to a conservation intervention can hinder conservation efforts (Lim *et al.*, 2017). In this case the price increase of e.g., timber following future logging bans or other protective measures such as protected areas might be counterbalanced by illegal trade and enhanced logging elsewhere ("leakage") and these unintended feedbacks on timber supply via market responses could be amplified even further if interventions shift the competitive ratio of efficient to non-efficient producers. Leakage effect from protected areas could also take place, when protected areas reduce threats within their boundaries by displacing a part of these threats into adjacent areas (Renwick *et al.*, 2015).

One of the key interactions between climate change and socio-economic changes is human population distribution and mobility. Climate change-induced migration, also referred to as "environmental migration" (Black *et al.*, 2011), can exert additional pressure on the environment in regions of migratory influx of people, which in turn exacerbates degradation of resources. Likely, migrants would choose urban or developed areas as their destinations (Tacoli, 2009). Enhanced pressure on resources around cities (see 4.3.3) following the influx of large number of people might lead to further environmental degradation, and pressure of people to move elsewhere. There are inherent difficulties in explicitly monitoring and predicting the effects of environmental migration caused by migration due to lack of comprehensive data (Kniveton *et al.*, 2008). However, evidence from the past (including non-environmental migration) can already illustrate the potential impacts (Reuveny, 2007).

Changes in value systems and lifestyle, sense of nature and loss of indigenous or local knowledge can be side effects of globalization and commercialization that ultimately impacts the GQL which in turn leads to more exploitation of natural resources (Hubacek *et al.*, 2009; Reyes-García *et al.*, 2013; Uniyal *et al.*, 2003; Van der Hoeven *et al.*, 2013). Robust identification and quantification of feedbacks is a challenge for future scenario projections, in part because of teleconnections and telecoupling that need to be considered (Liu *et al.*, 2013). Both are interactions over distances; teleconnections refer often to interactions in the natural environment such as through atmospheric transport or ocean currents, while telecoupling explicitly acknowledges that in today's world interactions occur in coupled human-environment systems (Liu *et al.*, 2013; Robinson *et al.*, 2017). Global scale scenarios and models that would allow to assess the complex interactions between nature, NCP and GQL, and to identify the role of amplifying or damping feedbacks not only locally but also between regions do not yet exist.

4.5.3 Trade-offs

The use of a given ecosystem service by human societies affects in most cases the availability of other ecosystem services. In many cases trade-offs arise, especially between material NCP vs. regulating NCP and biodiversity (see sections 4.3.2 and 4.3.3; Bennett *et al.*, 2009; Bonsch *et al.*, 2016; Carpenter *et al.*, 2017; Clark *et al.*, 2017; Di Minin *et al.*, 2017; Krause *et al.*, 2017; Lafortezza & Chen, 2016; Powell & Lenton, 2013; Seppelt *et al.*, 2013; Tscharntke *et al.*, 2012; Vogdrup-Schmidt *et al.*, 2017). Similar results have been found across all the IPBES regional assessments (IPBES, 2018b, 2018e, 2018c, 2018d) and UNEP's Global Environmental Outlooks (e.g., UNEP, 2012). In most future scenarios, the demand for material NCP increases because of population growth and consumption pattern changes (Popp *et al.*, 2017), which can be considered principal drivers for the declines in regulating NCP and biodiversity. In absence of targeted policy, future global demand for food, energy, climate and biodiversity may be very difficult to achieve simultaneously (e.g., Henry *et al.*, 2018; Obersteiner *et al.*, 2016; von Stechow *et al.*, 2016). Trade-offs (but also co-benefits) in ecosystem service supply can be considered important components of feedback loops (see 4.5.2), since in the long term a substantial decrease in regulating services will also negatively affect provision of material services that depend on the regulating ones (Cavender-Bares *et al.*, 2015). For instance, the destruction of pollinator habitat as part of agricultural expansion or intensification, can lead to declines in food production (IPBES 2016b), resulting in the need for further agricultural expansion (and associated further loss of pollinator habitat). The implications of future trade-offs will be influenced by regionally specific biophysical settings in combination with cultural preferences and thus should be considered in decision-making (Cavender-Bares *et al.*, 2015) (see chapter 6). However, since scenarios and models for many NCP are non-existent or incipient, many trade-offs and synergies remain unknown (Mach *et al.*, 2015). In particular cultural services are usually not considered in scenarios development or in models (see section 4.3), therefore future trade-offs with material and non-material aspects are poorly understood.

Food, bioenergy and water

Increasing consumption of food, and associated terrestrial and marine food production sectors, are seen as a main driver of biodiversity loss. Overexploitation of wild marine resources is expected to increase in the future under current management schemes (Costello *et al.*, 2016; see section 4.2.2.3.1) but could be alleviated by the growth of the aquaculture sector (Merino *et al.*, 2012; Quaas *et al.*, 2016). However, aquaculture development is challenged by a number of trade-offs related to fishmeal provisioning (Blanchard *et al.*, 2017) from wild marine resources (and potential further decline of marine populations, especially those serving as prey for already overexploited marine predators) or from cereal and soya production affecting land-based food production. Terrestrial ecosystems are impacted through cropland expansion as well as intensification on existing agricultural land and associated inputs of water and fertilizer (Foley *et al.*, 2011; Tilman *et al.*, 2011; Tilman & Clark, 2015). The pressure on agricultural systems will be increasing not only due to the continued population growth but also due to projected changes in dietary preferences towards meat-based protein intake in many countries. Under continuation of current trends, global food, water or timber demands are estimated to increase by 30% (timber), 65% (food and feed) and 75% (water) by 2050 (van Vuuren *et al.*, 2015).

Land-based climate change mitigation requires additional land area (e.g. for bioenergy or reforestation), which is projected to be lowest in sustainability scenarios that assume changes in consumption patterns (e.g., 250-530 Mha, SSP1/RCP2.6), and highest in scenarios that describe a world with large regional competition (e.g., 250-1500 Mha, SSP4/RCP2.6) (Popp *et al.*, 2017). In view of food and water demands of a growing human population, the question remains whether (and where) the required land area would be available for large bioenergy plantations or afforestation/reforestation efforts. Likewise, large direct or indirect side effects have been shown to arise for the global terrestrial ecosystem carbon balance, and hence climate regulation, other ecosystem functionality and biodiversity (Bird *et al.*, 2013; Jantz *et al.*, 2015; Krause *et al.*, 2017; Kraxner *et al.*, 2013; Melillo *et al.*, 2009; Plevin *et al.*, 2010; Santangeli *et al.*, 2016). It is well documented that the use of ecosystem services regionally will impact ecosystem functioning and services in other regions (Jantz *et al.*, 2015; Krause *et al.*, 2017; Seppelt *et al.*, 2013; and see section 4.3.3). For tradeable goods, and in absence of changing demand, land-use change in a given region (for instance, converting land to bioenergy rather than food production) will result in compensatory land-use changes elsewhere (for instance, conversion of natural habitat to food production) (Bird *et al.*, 2013; Krause *et al.*, 2017; Kraxner *et al.*, 2013; Melillo *et al.*, 2009; Plevin *et al.*, 2010).

Future land-use change scenarios with Integrated Assessment Models (Popp *et al.*, 2017) assume that land for bioenergy growth or afforestation and reforestation can be freed up through continued strong increases of crop yields (Bijl *et al.*, 2017; Bonsch *et al.*, 2016; Humpenoder *et al.*, 2015; see also **Table 4.1.6**, section 4.1), but the environmental and societal issues associated with the intensification of agricultural production are insufficiently considered in these scenarios. For an end-of-century 300 EJ bioenergy target to be produced from plants, Bonsch *et al.* (2016) found a doubling of global agricultural water withdrawal and a bioenergy production area of 490 Mha, or a land requirement of 690 Mha if no irrigation of bioenergy plants is considered. The latter increased to approximately 1000 Mha land for bioenergy if technology effects on increased yields would be only half of those in bioenergy than in food crops (Bonsch *et al.*, 2016). Krause *et al.* (2017) found both increases and decreases in different ecosystem functioning in response to scenarios under a RCP2.6 umbrella that included large-scale land-related climate change mitigation efforts, with large variability across regions and land-use scenarios. Large nitrogen losses were simulated in response to fertiliser needs to support yield increases, indicative of air and water pollution. Competition for land in climate change mitigation scenarios based heavily on bioenergy production has also been shown to increase food prices (Kreidenweis *et al.*, 2016). Detrimental societal impacts will arise if these price increases cannot be met by economic growth. It has now been consistently demonstrated that regional surface temperature can be strongly affected by land cover change, arising from altered energy and momentum transfer between ecosystems and atmosphere, with either an increase or decrease in temperature depending on the geographic context (Alkama & Cescatti, 2016; Li *et al.*, 2015; Perugini *et al.*, 2017; Quesada *et al.*, 2017a). Thus, changes in surface climate arising from large-scale land cover change in mitigation efforts can regionally amplify or reduce climate change. Large-scale land-based climate change mitigation efforts need to take account of unintended consequences on ecosystems that could undermine climate regulation or provisioning of a range of important ecosystem services.

An important element of the SSP1/RCP2.6 scenarios which limit global warming to about 2°C is that much of agriculture and bioenergy production relocates from high-income temperate regions to low-income tropical ones (van Vuuren *et al.*, 2011) where most of freshwater diversity is concentrated (Tisseuil *et al.*, 2013). Deforestation, extraction of high amounts of water withdrawal for irrigation, and use of pesticides and fertilizers to increase productivity in expanding bioenergy croplands are known to adversely affect natural aquatic systems and their biodiversity, notably fishes through local extinctions and alteration of their community structure (sections 4.2.3.2; 4.2.3.3). Inland fisheries are particularly important in tropical developing countries and currently provide the major dietary protein source for well over half a billion people (FAO, 2016; Lynch *et al.*, 2016). An increase in bioenergy production in these low-income food-deficit countries is thus expected to strongly impact fisheries and compromise further their food security.

4.5.4 Co-benefits

In order to sustain and enhance the future supply of NCP, in particular between regulating and non-material contributions (Ament *et al.*, 2017; Hanspach *et al.*, 2017; Potts *et al.*, 2016; Vogdrup-Schmidt *et al.*, 2017), changes in consumption patterns, globally, alongside changes in supply has emerged as crucial in scenarios of ecosystem change, NCP and GQL. In this context, reduction of food waste and shifts in diets are most illustrative.

Enhancing efficiencies in the food system, including the reduction of food losses and waste that occurs at several stages in the food production system, has large potential to enhance food security in a world where still every third person is malnourished, and 815 million people are hungry (FAO *et al.*, 2018). It may also free up land for other uses such as for biodiversity conservation, and entail additional co-benefits such as reduced greenhouse gas emissions from the land sector, and reduced irrigation water needs which will also release pressure on freshwater pollution and biodiversity (Alexander *et al.*, 2017b; Godfray *et al.*, 2010; Kummu *et al.*, 2012; Pfister *et al.*, 2011; Smith *et al.*, 2013). Nearly one-quarter of total freshwater used today in food crop production could be spared if wastes and losses in the food system were minimized (Kummu *et al.*, 2012). Nearly 10% of the agricultural land area could be spared globally through halving consumer waste arising from over-consumption in some sectors of society (Alexander *et al.*, 2017b). For the period 1961-2011, waste and losses in the food system were estimated to sum to approximately 68 $GtCO_2$ equivalents (Porter *et al.*, 2016).

A number of studies address the potential of reducing future expansion of croplands and/or reducing environmental impacts from agriculture and pastures (especially climate regulation related to reduced greenhouse gas emissions) through changes in diets. Studies that explore dietary scenarios of either reduced consumption of animal protein (combined with a globally more equitable distribution of animal protein) or no consumption of animal protein estimate that between about 10% and 30% of today's area under agriculture could be freed for other purposes (Alexander *et al.*, 2016; Bijl *et al.*, 2017; Ridoutt *et al.*, 2017 and references therein; Roos *et al.*, 2017; Tilman & Clark, 2014; Wirsenius *et al.*, 2010). A further positive side effect of these dietary shifts are health benefits in overweight population categories (Roos *et al.*, 2017; Tilman & Clark, 2014). The evidence base on impacts of diets on biodiversity, arising from reduced agricultural expansion is limited and context specific; however, a consumption-change scenario that included, among other changes in lifestyle, a shift towards a more vegetarian diet found positive effect on biodiversity of terrestrial mammals, in particular those with large ranges (Visconti *et al.*, 2015).

Additional cost-efficient measures to address environmental challenges have been demonstrated in studies that investigated optimizing crop distribution or the combination of several climate change mitigation options, while respecting food and fiber demand and conservation needs (Davis *et al.*, 2017; Griscom *et al.*, 2017). Through the globally optimal distribution of major crops, agricultural water use could be reduced by 12-14%, in a process-based crop-water-model combined with spatial information on yields, with large co-benefits for calorie and nutrient supply (Davis *et al.*, 2017). In particular, a move from some of the main cereal and sugar crops to e.g. roots, tubers and nuts underpinned these positive impacts. While cultural barriers, such as dietary preferences, will prevent to reach these potential gains of reduced water loss and enhanced food security, the analysis nonetheless puts forward a cost-efficient strategy towards sustainable intensification that could maintain small-holder farm systems and avoid large investments in technology-driven agriculture. From the perspective of contributing towards the achievement of the 2°C warming goal, economically-constrained greenhouse-gas reduction measures in the agriculture and livestock sector were estimated to contribute 1.5-4.3 Gt CO_2-eq. a^{-1} emission reductions (Bustamante *et al.*, 2014; Smith *et al.*, 2013; Tubiello *et al.*, 2015), which can be substantially enhanced further if consumer demand measures were also included. Recently, a combination of 20 different management measures in forests, agricultural land and wetlands achieved a maximum reduction of ca. 11 Pg C_{eq} a^{-1} when constrained by food security, conservation considerations and cost-efficiency (Griscom *et al.*, 2017). In addition, the future of land use and its impacts on biodiversity and ecosystem services depends on opportunities for building climate-resilience across sectors, including fisheries and aquaculture production systems (Blanchard *et al.*, 2017). As fish production has been the fastest growing food industry for the last 40 years, outpacing growth in all other livestock sectors (Béné *et al.* 2015), adaptive sustainable fisheries management (Costello *et al.*, 2016; Gaines *et al.*, 2018) combined with the development of sustainable low input and low impact aquaculture could generate co-benefits for food security, conservation of biodiversity, and climate regulation.

4.5.5 Regime Shifts, Tipping Points and Planetary Boundaries

There is a growing body of evidence that socio-ecological systems can be pushed past certain limits, beyond which they are profoundly altered in their structure and functioning. These are variously referred to as "regimes shifts", "tipping points" and "moving beyond planetary boundaries" and can be caused by a number of mechanisms (see Table A4.5.3 in Appendix 4.5). In some cases, these shifts occur rapidly and are difficult to reverse (Hughes *et al.*, 2013). The term "regime shifts" encompasses most of the concepts found in the definitions of tipping points and planetary boundaries, and so it will be used throughout this section except in cases where the distinction between concepts is important (Hughes *et al.*, 2013; Leadley *et al.*, 2014).

In some cases, regime shifts arise from relatively well understood physical and biological processes or feedbacks (Table A4.5.2) and have been included in models. In many cases, however, regime shifts arise from the complex interplay and feedbacks between people and nature (Table A4.5.3), and in general have not been well accounted for in scenarios and models. In addition to the underlying mechanisms, the spatial and temporal scales of regime shifts are extremely important when assessing the importance of their impacts and the evidence base for their past, current and possible future occurrence (Hughes *et al.*, 2013; IPCC, 2018; Steffen *et al.*, 2018).

Regime shifts that occur over the span of several years to several decades are well documented at local to small regional scales and occur frequently in response to increasing human pressure. In some cases, these can be reasonably well foreseen with scenarios and models. These regime shifts have large impacts on nature, nature's contributions to people and good quality of life at local scales, but may also have important impacts at much larger scales when they occur in many places at the same time (Leadley *et al.*, 2014). The collapse of local and regional fisheries is a salient example in marine ecosystems. The accumulation of these collapses at local to regional scales has reached a point where a substantial fraction of the world's fisheries is either collapsed or near the limits at which they could collapse (section 4.2.2.3.1). Land degradation is a good example in terrestrial socio-ecological systems. Land degradation is often the result of complex human-nature interactions and therefore the causes of land degradation are not the same everywhere in the world (Table A4.5.3). Land degradation is, however, sufficiently widespread that it is "negatively impacting the well-being of at least 3.2 billion people" (IPBES, 2018a). The increasing widespread phenomena of eutrophication of ponds and lakes by excess nutrient input is an excellent example in freshwater ecosystems (section 4.2.3.3). The common characteristics of these examples are that i) there is a rapidly increasing number of areas affected by these regime shifts, to the point that they now have global scale implications for nature and people, ii) scenarios and models of business-as-usual trajectories indicate that the pressures driving these regime shifts will increase over the coming decades in many regions and iii) scenarios and models suggest there are plausible alternative pathways that avoid aggravation of these regime shifts and, in many cases, lead to partial restoration of these systems (e.g., land restauration scenarios in IPBES, 2018f; Leadley *et al.*, 2010).

There are several regime shifts at large regional scales underway that have been initiated by human disturbance and are projected to have direct impacts on biomes over the next several decades (Leadley *et al.*, 2010; Steffen *et al.*, 2018). There is strong evidence that large-scale regime shifts have begun for tropical coral reefs (section 4.2.2.2.2, **Box 4.2.3**), large-scale changes in marine communities and ecosystem function due to the loss of summer sea ice in the Arctic Ocean (sections 4.2.2.2.1 and 4.2.2.2.4); and degradation of permafrost and increasing woody vegetation in arctic tundra systems (Settele *et al.*, 2014; section 4.2.4.1.1). Models foresee rapid aggravation of these regime shifts over the coming century (IPCC, 2018; Leadley *et al.*, 2010; sections cited above). Further rapid, global-scale degradation of tropical coral reefs — which are driven by the combined impacts of climate change, ocean acidification, sea level rise, pollution and overexploitation — is of particular and immediate concern because of the severe impacts on biodiversity and because large human populations depend on coral reef ecosystems for food, income and shoreline protection (IPCC, 2018; see **Box 4.2.3** and section 4.3.2.1). Several other postulated regime shifts at large regional scales are more uncertain. For example, the large-scale collapse of the Amazonian rainforest has been postulated due to the combined effects of deforestation and climate change and regional scale feedbacks, but observational and experimental evidence, as well as modeling studies are equivocal about the likelihood of a large-scale regime shift (Settele *et al.*, 2014; section 4.2.4). There are also early signals of tree dieback in boreal forests due to climate change, and some models project large-scale boreal forest degradation over the coming century, but the spatial scale and magnitude of this regime shift remains speculative (Settele *et al.*, 2014). A key feature of these regime shifts is that they are driven in large part by climate change and/or rising atmospheric CO_2 concentrations and therefore require strong international actions to reduce greenhouse gas emissions (IPCC, 2018). However, adaptation to and attenuation of climate change impacts also require additional local and national scale efforts to reduce other pressures under biophysical and economic limits (e.g., Smith *et al.*, 2016).

The likelihood of the occurrence of regime shifts, tipping points, or boundaries being exceeded for biodiversity and ecosystem services at global scales are speculative. The planetary boundaries literature posits that there are a few indicators that can be used to identify boundaries beyond which the planet will leave the relatively stable "safe operating space" that it has operated in over the last 10 millennia (Hughes *et al.*, 2013). There is growing evidence that some indicators, especially for climate change, are useful for identifying potential global scale regime shifts (Steffen *et al.*, 2018), but there is little evidence yet for a global scale indicator for biodiversity loss or degradation of ecosystem integrity (Mace *et al.*, 2014). It has also been postulated that the Earth is approaching a global scale regime shift that would lead to a massive loss of biodiversity and incalculable impacts on people (Barnosky *et al.*, 2012; Brook *et al.*, 2013; Steffen *et al.*, 2018). The mechanisms for these Earth scale tipping points are not well defined and not included in any models (Hughes *et al.*, 2013), but the combined effects of several large-scale regime shifts including the irreversible melting of the Greenland ice sheet, the loss of the West Antarctic ice sheet and several other regime shifts could plausibly combine to create a shift to a very hot global climate regime once moderate levels of global warming have been exceeded (Steffen *et al.*, 2018). There are also plausible mechanisms leading to telecoupling between regions such as atmospheric transport, movements of organisms, or human migrations that can greatly increase the spatial extent or impact of regime shifts (Leadley *et al.*, 2014). While these global scale regime shifts and planetary boundaries are speculative, the potential magnitude and scale of the impacts are so large that further work to understand and model the underlying mechanisms is essential.

4.6 LINKS TO SUSTAINABLE DEVELOPMENT GOALS, AICHI BIODIVERSITY TARGETS AND OTHER INTERNATIONAL OBJECTIVES FOR NATURE AND NATURE'S CONTRIBUTIONS TO PEOPLE

4.6.1 How good will we be at reaching international biodiversity and sustainability targets beyond 2020?

Scope: How are scenarios and models addressing international biodiversity targets and sustainability goals and what insights do they provide? This section builds on Chapter 3 (Progress towards Aichi Biodiversity Targets) by looking at projections beyond 2020.

The Aichi Biodiversity Targets agreed to in the Strategic Plan for Biodiversity 2011–2020, targets in other multilateral environmental agreements, and the Sustainable Development Goals (SDGs) have been adopted to motivate actions to sustain nature and its contributions to the promotion of human well-being and sustainable development (Chapter 3). Although many of the SDGs do not explicitly focus on nature, with the notable exception of goals related to life below water and life on land (SDGs 14 and 15), the supply of multiple ecosystem services is critical to achieving many SDGs. And despite the fact that relatively few SDG targets (as currently expressed) map directly onto nature or its contribution to people, most Aichi Biodiversity Targets are clearly related to SDGs.

Analysis of the data sourced from the systematic literature review (Appendix A4.1.1) shows that despite the importance of SDGs and Aichi Biodiversity Targets for sustainability and human well-being, few scenario analyses have a specific focus on achieving them, at least at global scale. Scenarios of biodiversity and ecosystem services can contribute significantly to policy support in all the major phases of a policy cycle, including agenda setting and policy design (Ferrier *et al., 2016; IPBES, 2016b, figure SPM3)*. Several scenario and modeling analyses provide useful indications related to policy targets, albeit indirectly **(Figure 4.6.1)**, but the vast majority of these relate to species declines and extinctions, therefore informing only on Aichi Target 12 (conservation of threatened species) and

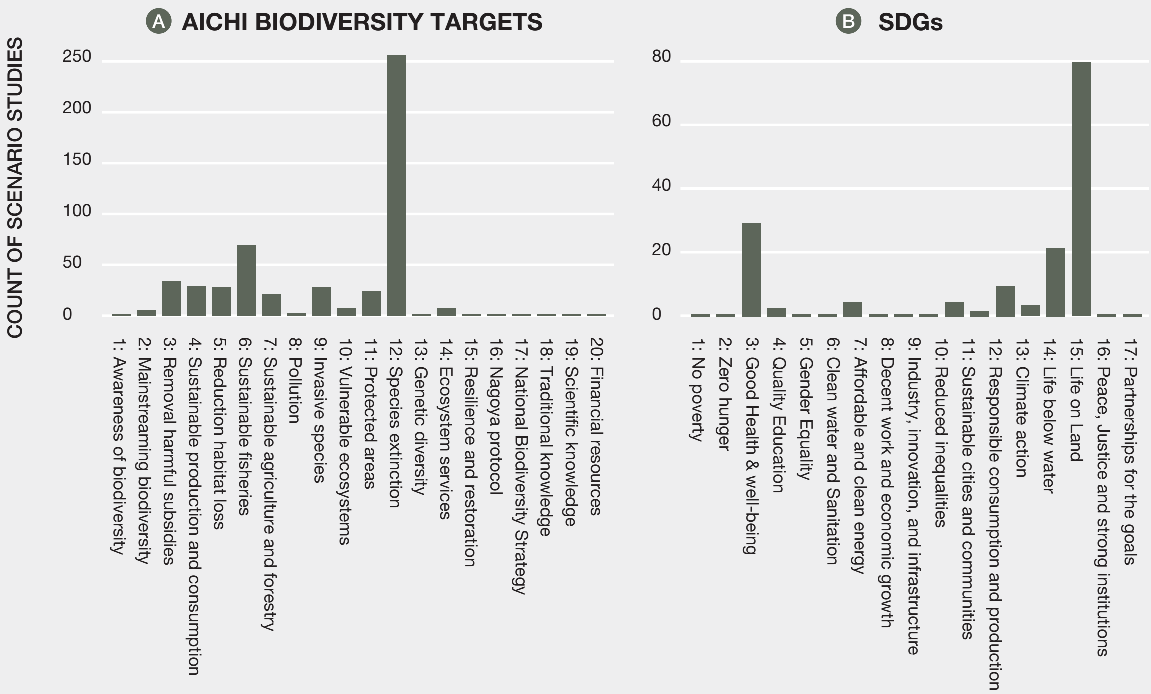


Figure 4 6 1 **Number of scenario studies addressing Aichi Biodiversity Targets A and SDG thematic policy areas B based on the systematic literature review carried out for this chapter (Appendix A4.1.1).**

a small subset of targets related to SDG 15 (life on land). The reason for this imbalance probably lies in the different level of development of methods in the research community. Models for projecting species distributions under climate scenarios (which relate to Target 12 and SDG 15) are well established and widely used in the literature, while the exploration of other targets and goals is hampered by the scarcity of appropriate models at global scale. Global scale scenarios specifically addressing Aichi Biodiversity Targets are scant **(Figure 4.6.1A)**, and most of them relate to Target 12 (conservation of threatened species) and 6 (sustainable fisheries). Scenarios addressing SDGs focus mostly on SDG 15 (life on land), 2 (zero hunger) and 14 (life below water), but this also reflects the fact that the focus of the systematic literature review for this chapter was restricted to biodiversity and ecosystem services, rather than encompassing other societal goals. Therefore, the SDGs other than 14 and 15 represented in **Figure 4.6.1B** were addressed in conjunction with SDG 14, 15 or both.

For Sustainable Development Goals, scenario analyses are usually sector-specific (Obersteiner *et al., 2016)*, and a review of 22 modelling case studies has shown that it would be unlikely that any scenario modelling exercise could cover all (Allen *et al., 2017)*. Most studies focus on environment-economy interactions, such as greenhouse gases (GHG) reduction and impacts of this on growth and employment, and consideration of broader social issues is limited (Allen *et al., 2017)*. Various models have been used to assess SDGs including top-down system dynamics, macro-economic and hybrid models as well as bottom-up sectoral models across multiple sectors such as energy, agriculture, transport, land use, etc. (Allen *et al.,* 2016, 2017).

Biodiversity targets have been missed in the past for 2010 (Butchart *et al.*, 2010), and the mid-term progress towards Aichi Biodiversity Targets for 2020 was insufficient (Tittensor *et al.*, 2014). The world is still far or very far from achieving most of the Aichi Biodiversity Targets by 2020 (Chapter 3). Evidence from the limited number of scenario analyses from the systematic literature review (Appendix A4.1.1) shows that these targets are unlikely to be achieved even at some point in the future in most scenarios (2050 and beyond). However, for most targets, delayed achievement in the future is possible under some scenarios **(Figure 4.6.2)**. Recent scenario research has explored the likelihood that global biodiversity targets can be achieved by steering from business-as-usual to more sustainable socio-economic development trajectories. For example, Visconti *et al.* (2016) have projected policy-relevant indicators (Living Planet Index, LPI, and indicator of species abundance, and Red List Index, RLI, an indicator of extinction risk) for large mammals to 2050, comparing a reference scenario to sustainability scenarios (van Vuuren *et al.*, 2015).

Figure 4.6.2 **Achievement of Aichi Biodiversity Targets in the future (2050 or beyond) across different global scale scenarios, based on our systematic literature review (Appendix A4.1.1).**

N: number of indicators, with number of studies in parenthesis, each study usually projecting several different indicators. Many scenarios dealing with Aichi Biodiversity Targets did not report results in a way that could be interpreted as level of target achievement, therefore the numbers here are smaller than in **Figure 4.6.1**.

They showed that after a mid-term increase until 2030, biodiversity indicators would decline again afterwards as the projected effects of climate change outpace mitigation actions. This analysis showcases how scenario modelling links long-term results to short- and medium-term action. It has been proposed that for achieving future targets, bold goals like the CBD 2050 Vision be adopted, and that integrative policies for sustainable production and consumption (e.g., a shift towards a more balanced diet, Chapter 5) be adopted (Mace *et al.*, 2018).

The global results on achievement of biodiversity targets do not scale down to the IPBES regions where the same topic has been addressed. The IPBES regional assessment for Africa (IPBES, 2018g) found low likelihood to ever achieve most Aichi Biodiversity Targets, except Target 1 (awareness of biodiversity) and 14 (ecosystem services), for which the regional trend is positive. Under the "fortress world" archetype scenario (similar in characteristics to the "regional competition" archetype defined in this chapter, section 4.1), the trend in Africa is negative for all Targets. For Europe and Central Asia, sustainability scenarios are expected to achieve most Aichi Biodiversity Targets, but still fail a few (in particular Targets 1, awareness of biodiversity, and 17, national biodiversity strategies) (IPBES, 2018i). The information is not available for other IPBES regions.

If the global socio-economic development continues according to a business-as-usual scenario, it is likely that we will fail to achieve several biodiversity-related SDGs (SDG 14, Life below water, and 15, Life on land). Three-quarters of the scenario and models that address SDG 15 project that we will be far or very far from achieving it. A similar outcome is projected for SDG 14 (**Figure 4.6.3**). In Europe and Central Asia scenarios of sustainable production and consumption are expected to achieve most SDGs (IPBES, 2018i). In this region, the economic optimism archetype scenarios are expected to achieve most SDGs, but notably fail SDG 14 and 15. A recent study stressed that under the current trajectory of socio-economic development, progress in SDGs related to poverty and social inclusion happens at the expense of the environment, and this will lead to missing environmental SDGs in most of the world countries (**Figure 4.6.4**; Spaiser *et al.*, 2017). This is attributed to the

Figure 4 6 3 **Achievement of SDGs across different global scale scenarios, based on our systematic literature review (Appendix A4.1.1).**

N: number of indicators, with number of studies in parenthesis, each study usually projecting several different scenarios. Many scenarios dealing with SDGs did not report results in a way that could be interpreted as level of target achievement, therefore the numbers here are smaller than in **Figure 4.6.1**. The systematic literature review focused on Nature and NCP, therefore SDGs other than 14 and 15 were captured only if they were assessed in conjunction with them.

focus on economic growth and consumption as means for development.

Several emerging issues have been identified as influential to the achievement of the SDGs. These include new scientific knowledge, new technological development, new scales or accelerated rates of impact, a heightened level of awareness and new ways to respond to a known issue (UN, 2016). Despite the uncertainty associated with these emerging issues, various aspects have been identified as necessary to achieve the SDGs. First, measuring progress at all scales, and integrating global targets with local policies is fundamental towards achieving the SDGs (Biermann *et al., 2017)*. Goal 17 on revitalizing the "global partnership", for example, will require increased funding and clear leadership (Biermann *et al., 2017)*. Increased funding is also one of the fundamental needs to achieve the SDGs in some regions within the African Continent (Kedir, 2017). Controlling consumption and demand remains an important issue. A recent work combing literature review and a comparison exercise of integrated energy-economy-climate models, AMPERE, found out that in order to achieve a 2ºC scenario, lowering the global growth of energy demand is key according to energy-economy-climate models (von Stechow *et al., 2016)*. Several local scenario studies provide useful insights towards achieving SDGs. In South Asia, industrial transformation, sustainable agriculture and innovations have been identified as key aspects to achieve SDGs (Kumar *et al., 2016)*. Participatory scenarios to achieve visions coherent to SDGs and to adequately adapt to future climate change impacts have also been applied with local communities in Indonesia (Butler *et al., 2015)*.

Scenarios have proven useful to identify and analyze synergies and trade-offs among biodiversity targets and SDGs. Glover and Hernández (2016) applied foresight techniques with experts in international development studies and found out that SDGs are not necessarily harmonious and mutually reinforcing but that trade-offs exist. According to this study, without strategic planning, advances towards one SDG might lead to negative consequences to others. Sustainable Consumption and Production policies (SDG 12), assessed through the GLOBIOM model, shows the need of inclusive policies among global development and

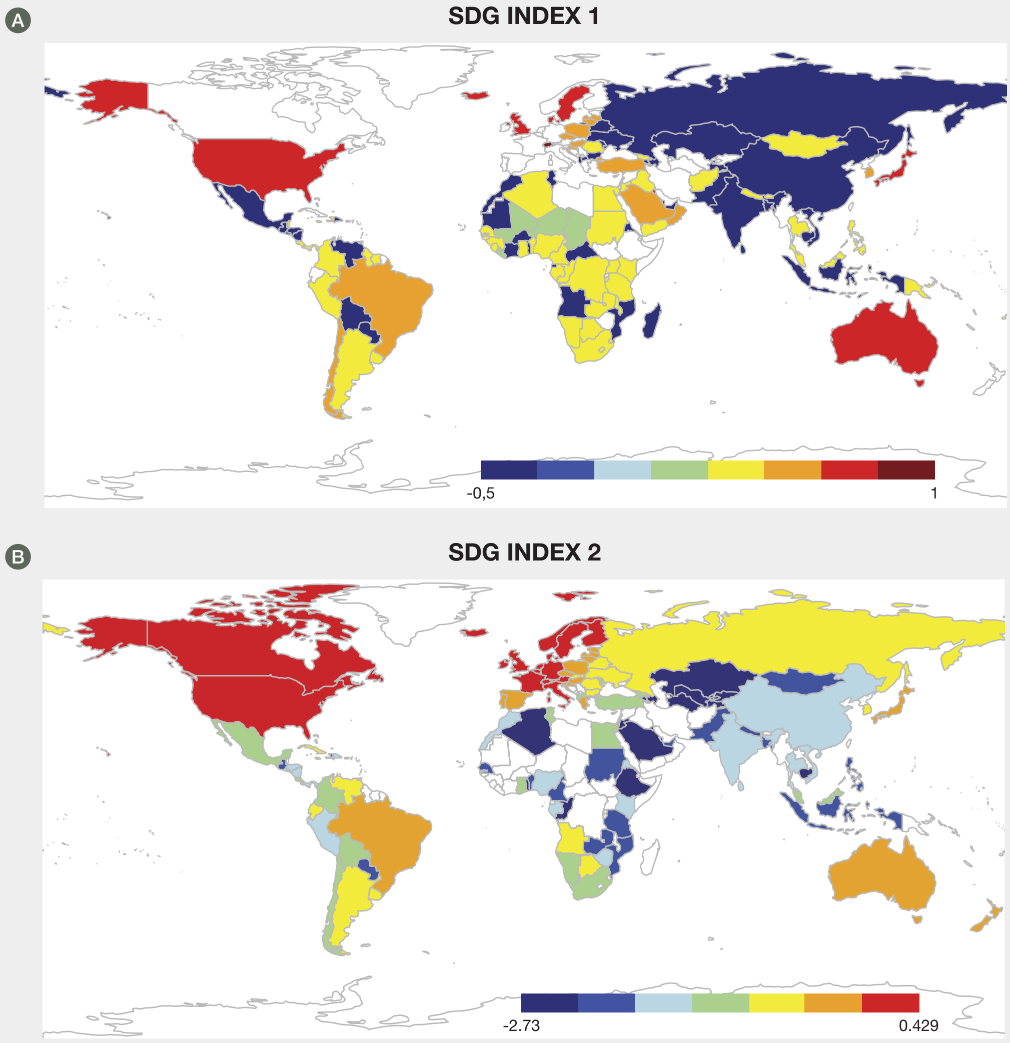


Figure 4 6 4 **World maps with countries being coloured based on an SDG index scores for 2011.**

The SDG index is based on the rate of change in three variables (child mortality, education, and CO_2 emissions) representing the three SDG pillars (ending poverty, social inclusion and environment). White colour indicates that an index could not be calculated, due to missing data in one or several of the predictors in the modelling approach used by Spaiser *et al.* (2017). The modelling approach used country and year specific data and combined confirmatory and exploratory factor analysis with dynamic systems modelling. Panel A reveals which factors are associated with development and negative values indicate a reduction of child mortality and an increase in education, as well as increased CO_2 emissions. Countries such as Russia, China and India present negative values of this indicator, showing that they perform well at reducing poverty and increasing socio-economic inclusion, but with associated environmental trade-offs in terms of CO_2 emissions. Developed countries like Australia, USA and UK, which have high levels of socio-economic development, show little room for improvement of their SDG index. Other countries like Brazil, Thailand and South Africa seem to present slower socio-economic development trends. Panel B uses a similar modelling approach but combined with a Bayesian model. The SDG index shows similar results for rich countries. However, contrarily to results of panel B, in panel A Russia presents a slow socio-economic development and several African countries such as Angola and Kenya make some progress in terms of socio-economic development. The trade-off between environment and the other two SDG pillars means that based on this analysis, under the current socio-economic model not all SDGs can be achieved together.

conservation agendas to minimize trade-offs and foster synergies (Obersteiner *et al.*, 2016). In another recent study using the IMAGE integrated assessment model, van Vuuren *et al.* (2015) have shown that achieving 2050 goals for both biodiversity and hunger would require a substantial increase in agricultural productivity per hectare, to accommodate a 50-70% increase in demand for food while halting the conversion of natural habitats. Another study found that implementing ambitious protected area expansion plans, under business-as-usual socio-economic trends, may result in a shortfall in productive land, as well as displacement of agricultural areas with consequential socio-economic

Table 4 6 1 **Synergies and trade-offs between different sustainability objectives.**

Colours indicate synergies (green) and trade-offs (red) in various intensities. Source: van Vuuren *et al.* (2015).

	Eradicate hunger	Halting biodiversity loss	Access to energy	Reduce air pollution	Mitigate climate change	Access to clean water	Balance nitrogen cycle
Eradicate hunger					More emissions from increased production (fertiliser. land expansion tractors) (*)	Increased water use for agriculture (*)	More emissions from increased production (fertiliser, manure (*)
Halting biodiversity loss	Less land for food production (*) Preservation or ecosystem services helps safeguard long-term food supply			Intact ecosystems contribute to better air quality	Fewer CO_2 emissions from land conversion and agriculture, new CO_2 sinks (*)	More gradual and uniform water flow, cleaner water Increased water use by permanent vegetation	More contribution of ecosystems in balancing nitrogen cycle
Access to energy	Increases income opportunities due to reduced time for fuel collection, better health	Less disturbance of local biodiversity for food collection		Less indoor and urban air pollution (*)	New emissions from modern energy offset by reduced traditional energy emissions (*)	Water requirement for power generation (small) (*)	
Reduce air pollution	Less negative impact of air pollution on crop yields	Less air pollutions impacts on biodiversity (*)	Higher energy prices		Depends on which air pollutants are reduced (*)	Less water pollution	Helps to reduce nitrogen deposition (*)
Mitigate climate change	Reduces negative impacts on yields (but also positive impacts) (*) Bio-energy competes for land with food production	Reduces negative impacts of climate change (*) Additional land for bio-energy (*)	Higher energy prices (*)	Less emissions of air pollutants due to lower fossil fuel use (*)		Negative impacts on precipitation patterns and evapotranspi-ration reduced (*)	Some positive impact N_2O emission reduction (*)
Access to clean water	Improved water for cooking Competition between agriculture and domestic purpose						
Balance nitrogen cycle	Reduction of fertiliser use (but also prevents toxic fertiliser levels)	Reduces pollution		Reduces air pollution	Some reduction of N_2O emissions		

Note: *denotes that the linkages is addressed quantitatively by the modelling framework.

impacts (Visconti *et al.*, 2015). Eradicating extreme poverty however, does not necessarily mean jeopardizing climate targets, even in the absence of specific climate policies and technological innovations (Hubacek *et al.*, 2017). Di Marco *et al.* (2016) explored the interactions between Aichi Biodiversity Targets 5 (reducing the loss of natural habitat), 11 (expanding the global coverage of protected areas) and 12 (conserving threatened species). They showed that the expansion of the global protected areas to 17% of land area resulted in different priorities of sites depending on whether the goal was to reduce habitat loss or conserve species. In addition, expanding protected area coverage to 17% to conserve threatened species would result in safeguarding 30% more carbon stock than targeting areas under high deforestation rates. The reason is that areas under rapid deforestation are not necessarily those with the highest capacity to stock carbon. While the figures relate to the Aichi Biodiversity Targets for 2020, the same trade-offs are likely to apply to post-2020 biodiversity targets. **Table 4.6.1** highlights some of the most significant synergies and trade-offs between different objectives associated with the Sustainable Development Goals.

Further modelling on policy targets that explicitly embodies nature into scenarios is of outmost importance. Scenarios developed for global environmental assessments have explored impacts of direct and indirect drivers on nature but have not embedded nature in the scenario itself. The effects of alternative pathways of socioeconomic development on nature have thus been assessed as one-way outcomes, ignoring the possible feedbacks of nature on the system (Rosa *et al.*, 2017). Existing scenarios ignore policy objectives related to nature protection. As targets for human development become increasingly connected with targets for nature, such as in the SDGs, the next generation of scenarios should explore alternative pathways to reach these intertwined targets and address feedbacks between nature, nature's contributions to people, and human well-being. Several desirable properties of this new generation of scenarios have been identified, including the use of participatory approaches, the integration of stakeholders from multiple sectors (for example, fisheries, agriculture, forestry) (Rosa *et al.*, 2017), and addressing decision makers from the local to the global scale (Biermann *et al.*, 2017).

4.6.2 How can the evidence from scenarios contribute to the development of future biodiversity targets and the 2050 vision?

Scope: How can scenarios and models help to reformulate the new set of targets? To address this issue, this section uses the Aichi Biodiversity Targets for 2020 as templates for setting the next generation of targets. Only a subset of the targets is discussed, with the purpose to demonstrate the type of considerations that should underpin the new targets. Existing scenarios and models for biodiversity and ecosystem services are used to explore: i) how targets can be formulated in ways that can more easily be understood and evaluated by both policymakers and practitioners; ii) which kinds of indicators, that come from observations and scenarios, can be used to evaluate progress towards the objectives of this target; and iii) what scenarios and models tell us about ambitious vs. aspirational targets, i.e. whether they can be achieved under plausible conditions represented by a variety of exploratory scenarios of societal and economic development.

4.6.2.1 Habitat loss and degradation (Target 5)

"By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced."

Analyses based on satellite remote sensing identified over the period 2000-2012 a net global loss of ca. 1.5 million km^2 of forest (Hansen *et al.*, 2013), including substantial loss of structurally intact pan-tropical forests (Tyukavina *et al.*, 2016). At current trends, even the target specified in the New York Declaration of Forests (to halve the rate of natural forest loss by 2020) is highly unlikely to be achieved (Zarin *et al.*, 2016). Under most future scenarios, the future net loss of natural habitats is partly counterbalanced by secondary regrowth. This is true for both forest and non-forest natural habitats (Hurtt *et al.*, 2011). Secondary habitat types typically host a fraction of the biodiversity present in primary habitats of the same type (Alkemade *et al.*, 2009; Newbold *et al.*, 2013), and this fraction depends on the integrity and age of the secondary vegetation. Therefore, numeric targets for the rate of loss of natural habitat are insufficient to capture the complex dynamics of habitat change, and the proportion of biodiversity that they retain compared to pristine habitats should also be considered.

From a scenario and modelling perspective, assessing the current and future state of forest globally is challenging for a number of reasons: 1) very different classifications as to what is a forest and which forest is considered intact, which one degraded (Alexander *et al.*, 2017c; Thompson *et al.*, 2013); 2) Most land-use change scenarios do not yet tend to consider environmental policies such as the Aichi Biodiversity Targets, the SDGs or REDD+ (Alexander *et al.*, 2017c; Eitelberg *et al.*, 2016, 2015; Popp *et al.*, 2017); 3) Integrated Assessment models that are often used to produce scenarios typically do not have the forest sector explicitly included at their core (Schmitz *et al.*, 2014); 4) Models that seek to assess future ecosystems from state of, e.g., carbon cycle and climate regulation perspective do not yet account well for forest (or other habitat) management (Arneth *et al.*, 2017).

In principle, activities to achieve Target 5 could have large co-benefits with achieving Targets 11 and 17, if protected area expansion could be dedicated to cover habitats of both high species density (in particular threatened or rare species) and regions of high carbon density (Di Marco *et al.*, 2016). Under otherwise unchanged conditions, scenarios in which multiple demands for land resources are aimed to be met resulted in intensification of croplands (adding to the "land sharing/land sparing" debate) and enhanced areas with tree cover (Eitelberg *et al.*, 2016). However, accounting for demand for protected area had no effect on reducing the projected loss of grassland, compared to business-as-usual (Eitelberg *et al.*, 2016). Maximizing forest habitat conservation as well as forest species conservation was estimated to be possible in 73% of the area identified to be also most appropriate for expanding the current protected area to meet Target 11 (Di Marco *et al.*, 2016).

Recent and projected trends in population growth and lifestyle (e.g., dietary changes), jointly with enhanced requirements for bioenergy crops are expected to maintain large pressures on further cropland expansion (Alexander *et al.*, 2017a; Eitelberg *et al.*, 2015). Agriculture is one of the largest drivers of biodiversity loss, and a large source of greenhouse gases and pollutants (McLaughlin & Kinzelbach, 2015; Newbold *et al.*, 2015). Therefore, achieving conservation goals alongside meeting demand for food and fibre, water, bioenergy and climate mitigation will require a dedicated effort that considers both changes in supply and demand, as well as equitable trade (Alexander *et al.*, 2017a; McLaughlin & Kinzelbach, 2015).

4.6.2.2 Sustainable fisheries (Target 6)

"By 2020, all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches [...]."

Whilst the objectives of Target 6 are relatively clear, some terms remain imprecise. The primary facets of the Target which remain loosely defined are the concepts of 'safe ecological limits' and 'no significant adverse impacts' (also the issue of 'vulnerable' ecosystems; see Target 10). 'Safe ecological limits' as a term lacks indication of whether these limits are structural (e.g. maintenance of facets such as ecosystem trophic structure or species composition) or functional (e.g. continued provision of goods and services). Without clarification, it is then difficult to know what aspects of ecosystems should be maintained, nor the level of degradation that is to be tolerated. Furthermore, the margins of safety are not clearly specified –how are these limits to be measured, quantified, and monitored? How close to the 'safe ecological limit' is acceptable? Finally, the term "safe limits" has been used with many contexts including the planetary boundary framework (Steffen *et al.*, 2015) and, therefore, might benefit from clarification. It is important not to confound 'safe ecological limits' and 'safe limits for humanity' since these refer to very different reference baselines, as well as very contrasted spatial and temporal scales.

Regarding 'no significant adverse impacts', the lack of specificity here is to do with the meaning of the word 'significant' (note that Target 5 also includes this terminology). Scientifically, 'significant' generally has a statistical meaning, indicating evidence at some level of likelihood that an effect is not attributable to chance. It seems unlikely that this is the intended meaning here, but significant can be so broadly interpreted as to make consistency of application across national and regional scales extremely challenging.

Quantification of progress towards this target through appropriate indicators has shown that at least some indicators exist for monitoring resource state (e.g., the proportion of fish stocks within safe biological limits), the pressures on it (e.g., global effort in bottom trawling), and fisheries responses to pressures on fish stocks (e.g. Marine Stewardship Council certified fisheries). However, indicators of whole ecosystem (as opposed to stock) status and recovery plans remain limited or absent, and the scope and alignment of existing indicators varies. Recent focus has been put on ecosystem-based indicators for assessing the state of exploited species and the ecosystems they are embedded in (Coll *et al.*, 2016; Shin *et al.*, 2012), some of which have been retained in the list of IPBES "Highlighted indicators" but still lack global scale coverage for nations to be able to report routinely (proportion of predators, mean fish size).

Projecting plausible futures for marine and aquatic biological resources is aided by the fact that there has been a long history of model development for these systems, with a particular profusion of models emerging over the past decade or so (Fulton, 2010). Models range from single species stock assessment models to whole ecosystem approaches, and in some cases such models incorporate large parts of the socio-economic and management components as well as the biological ones (Nielsen *et al.*, 2018). The heterogeneity of models is also beginning to be addressed by applying standardised ensemble modelling approaches across specified scenarios (Tittensor *et al.*, 2018b), akin to model intercomparison studies in the climate and earth science communities. Perhaps more challenging is the specification of socio-economic storylines that can then be translated into projections that can be used to force ecosystem models. While storylines have recently been in development at both regional (CERES, 2016) and global (Maury *et al.*, 2017) scales, specifying how the developments in economics, management, and governance that are outlined in scenarios can then be used to force models, especially spatially explicit models, is difficult. Furthermore, management and stewardship of marine resources remain varied among nations in terms of capacity, approach, and effectiveness (Bundy *et al.*, 2017). Management regimes can also change radically and rapidly in response to changes in national policy environments (e.g., the enactment and amendments of the U. S. Magnuson-Stevens Fishery Conservation and Management Act), and resource management plays an integral role in terms of the status of both target species and ecosystems (FAO, 2016), and furthermore adaptation to a changing climate. Nonetheless, the continued development of scenarios, together with the broad and growing range of marine ecosystem models at multiple scales, suggests that Target 6 can be usefully and increasingly informed by their application.

Broadly speaking, the development of future policy targets needs to further incorporate the role of climate change on the sustainability and use of aquatic resources. Furthermore, objectives may need to be reframed or at least clarified in order to address the challenges of measuring 'significant adverse impacts' and 'safe ecological limits' whilst still allowing for national level variation in how objectives are attained and recognizing differences in capacity for stewardship of aquatic resources. When specifying targets, it also needs to be made clear whether the goal is maintaining ecosystem structure, the provision of goods and services (including contributions to food security), or both. Currently, there is also potential overlap between Targets 6 and 7, in that Target 6 includes the management and harvest of fish and invertebrate stocks and aquatic plants, which will be increasingly linked to the development of aquaculture in the future that is addressed in Target 7 (section 4.2.2.3.1). Given the continued growth in the importance of aquaculture, its impacts on broader ecosystem health, including indirect effects such as fishing wild stocks to provide fishmeal for aquaculture (not explicitly mentioned in Target 7, but implicitly included in Target 6) needs to be further integrated into future targets. Similarly, at present there is overlap with Target 10, since anthropogenic impacts on coral reefs (and other vulnerable aquatic ecosystems) include those integrated into Target 6.

4.6.2.3 Sustainable agriculture (Target 7)

"By 2020, areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity."

The scientific community has been engaged in a controversial debate about whether biodiversity conservation can better be achieved by improving habitat availability and quality on farmland (i.e. through wildlife-friendly farming – "land sharing"), or whether it is dependent on natural habitat and thus requires high-yielding agriculture to reduce land requirements (i.e. sparing land for nature – "land sparing") (Fischer *et al.*, 2014; Phalan *et al.*, 2011). But recently consensus has started to develop that convey that different strategies are needed in different contexts and for different conservation goals (Ramankutty & Rhemtulla, 2012) and that sustainable agricultural management includes both measures to increase on-farm habitat quality, as well as increasing productivity while minimizing harm to biodiversity (Clough *et al.*, 2011; Kremen, 2015; Seppelt *et al.*, 2016).

Currently, however, it appears unlikely that we will achieve either wildlife-friendly farming or stop the conversion of natural habitats by 2050 if current trends continue. Crop production is projected to increase by 50-100% by 2050 to meet future demand under current population and diet trends (Alexandratos & Bruinsma, 2012; Tallis *et al.*, 2018; Tilman *et al.*, 2011). According to a comparison of the best state-of-the-art land-use models, the combined effect of projected climate change, as well as middle of the road population and economic development projections, would result in an expansion of global cropland by about 20% by 2050 (Schmitz *et al.*, 2014). Business-as-usual trends would also result in the further conversion of >50% of natural habitats to croplands in important ecoregions like Mediterranean forests and temperate grasslands (Tallis *et al.*, 2018). In addition to this conversion of natural habitats, fertilizer use, which has large negative impacts on biodiversity and ecosystem services especially in freshwater systems, is projected to increase by 58% by 2050 (Alexandratos & Bruinsma, 2012). Wildlife-friendly farming methods are still restricted to comparatively small areas: only about 1% of global agricultural land is, for example, managed organically (Willer & Lernoud, 2017), and approximately 7.5% of it is managed with agroforestry with more than 50% tree cover (Zomer *et al.*, 2009).

Numerous analyses show, however, that achieving sustainable agriculture that produces enough food for everyone while ensuring conservation of biodiversity is possible, if far-reaching food system changes are implemented. Recent scenario analyses have shown that globally enough food could be produced for everyone in 2050 on existing agricultural land, while halting deforestation and protecting 17% of the world's terrestrial habitats if we shifted towards more sustainable diets, reduced food waste and closed yield gaps (Erb *et al.*, 2016; Foley *et al.*, 2011; Muller *et al.*, 2017; Tallis *et al.*, 2018; West *et al.*, 2014). A recent study, for example, estimated that by closing yield gaps and optimizing where crops are grown, >50% of each of the world's biomes could be set aside, while still producing enough food for all people in 2050 (Tallis *et al.*, 2018). Similarly, organic agriculture could be used as a wildlife-friendly agricultural management strategy, if combined with other food system strategies, e.g. reductions in food waste and changes in livestock feed composition, to provide enough food for people in 2050 on current agricultural land while also reducing pesticide use and nitrogen pollution (Muller *et al.*, 2017). These various scenarios show that both land-sharing and land-sparing strategies would be possible to help conserve biodiversity while feeding humanity if broad food system changes were implemented.

4.6.2.4 Vulnerable ecosystems (Coral Reefs) (Target 10)

"By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning."

The Global Biodiversity Outlook 4 (GBO-4), which evaluated progress towards the Aichi Biodiversity Targets in 2014, focused on the aspects related to climate change impacts on tropical coral reefs and the importance of reducing multiple pressures to minimize these impacts – and concluded that this target had been missed. Observations, experiments and models provide sound arguments for maintaining a strong priority on tropical coral reefs due to their exceptional vulnerability to climate change (IPCC, 2018). Warm-water coral reefs are one of the most biodiverse marine ecosystems in the world and provide a wide range of ecosystem services, especially to people living in tropical regions (CBD, 2014). They are also one of the most rapidly degrading ecosystems globally due to a combination of many pressures including pollution, overexploitation and ocean warming (see sections 4.2.2.2.2, **Box 4.2.3** in section 4.2.2.3.1; Butchart *et al.*, 2010; CBD, 2014; IPCC, 2018). Models and observations indicate that tropical coral reefs are exceptionally vulnerable to future ocean acidification and warming due to their very high sensitivity to these factors compared to most other systems (Bay *et al.*, 2017; Gattuso *et al.*, 2015; IPCC, 2018). Models project that there will be significant negative impacts even if the most ambitious targets of the Paris agreement of limiting global warming to 1.5°C are achieved (IPCC, 2018). For higher CO_2 emissions and warming scenarios, models project severe degradation of nearly all tropical coral reefs and the limits of natural adaptation and ecosystem management to preserve the integrity of these ecosystems will be exceeded (Bay *et al.*, 2017; Gattuso *et al.*, 2015).

Observations and models also indicate that all ecosystems are vulnerable to climate change or acidification to some extent (IPCC, 2014). Some ecosystems are projected to be particularly vulnerable because exposure to climate change is high – these include Arctic tundra and ocean ecosystems where warming is projected to be higher than elsewhere on the globe (Settele *et al.*, 2014). Other ecosystems are projected to be especially vulnerable due to their high sensitivity to climate change or acidification, and little space for adaptation – in addition to coral reefs, these include mountain terrestrial and freshwater ecosystems, tropical ecosystems, and deep oceans (section 4.2.2.2.3; Settele *et al.*, 2014). All ecosystems of the world are projected to experience changes in species composition and abundance due to species ranges shifts and modifications of ecosystem function caused by rising CO_2 and climate change (IPCC, 2014). A consensus ranking of ecosystem vulnerability to climate change is not available due to unsettled scientific debates and uncertainty in modelled impacts (e.g., Settele *et al.*, 2014).

Because there is a lack of consensus on the vulnerability of ecosystems to climate change outside of coral reefs, this target currently suffers from a lack of clarity. This target has been dubbed "Vulnerable Ecosystems" for shorthand (Aichi Passport, UNEP-WCMC) and covers "other vulnerable ecosystems", which poses problems of definition because all ecosystems are vulnerable to climate change or acidification to a greater or lesser extent (IPCC, 2014). As such, this target has been associated with a loosely related set of indicators, some very narrow and others overly broad, that are used to assess progress towards this target; for example, the Biodiversity Indicators Partnership lists the Ocean Health Index (extremely broad), Climatic impacts on European and North American birds (taxonomically and spatially restricted), Red List Index for reef-building corals (not well targeted for climate change impacts), and Cumulative Human Impacts on Marine Ecosystems (exceptionally broad) as indicators for this target.

There is strong evidence that reducing other stresses on ecosystems will generally improve the capacity of ecosystems to adapt to climate change. For tropical coral reefs, reducing nutrient loading and maintaining or reinforcing herbivorous fish populations helps reduce the competition by algae and these and other measures are projected to substantially improve the capacity of coral reefs to maintain their integrity in the face of climate change (Box 4.3.2 in section 2.2.3.1; Gattuso *et al.*, 2015; Kennedy *et al.*, 2013). Other examples include the importance of halting terrestrial habitat fragmentation and increasing connectivity between natural habitats to allow species to move so that they can track favourable climates (Imbach *et al.*, 2013).

Public policy and ecosystem management strategies for adaptation to climate change are being developed and deployed for some ecosystems. Forest managers, for example, have been very active in developing climate adaptation strategies based on projected impacts of climate change on trees, some of which depend on maintaining or reinforcing genetic and species diversity of trees and protecting ecosystem integrity (Keenan, 2017). However, not all climate change adaptation strategies for ecosystems are biodiversity friendly; for example, some forest adaptation strategies put an emphasis on the introduction of fast-growing alien tree species (Keenan, 2017). Evidence-based action plans for tropical coral reefs are in place for some reef systems, and most put an emphasis on maintaining ecosystem integrity as a key to enhancing resilience and resistance to climate change and acidification (e.g., Great Barrier Reef Climate Change Adaptation Strategy and Action Plan, see also Gattuso *et al.*, 2015; Kennedy *et al.*, 2013). Scientists are also actively exploring other strategies requiring much more active intervention such as protective sun screens, cultivation of warming adapted corals and climate geoengineering (Kwiatkowski *et al.*, 2015; van Oppen *et al.*, 2015).

These considerations suggest that future policy targets could highlight the relationships between climate change adaptation and biodiversity protection. They could include relatively broad objectives that are common to all climate adaptation strategies for ecosystems, as well as a particular emphasis on tropical coral reefs, focusing on: the vital importance of meeting the 2°C goal, and if possible the 1.5°C goal of the Paris Agreement in order for adaptation to be effective in highly vulnerable ecosystems *(new emphasis)*; the need to reduce multiple pressures on all vulnerable ecosystems, so as to improve their resistance and resilience in the face of climate change and acidification *(maintained emphasis)*; the key role of developing and implementing climate change adaptation measures for all ecosystems with a wide range of stakeholders that take into account the protection of biodiversity and emphasize the importance of nature-based adaptation strategies *(new emphasis)*; the need to develop strategies of societal response to projected inevitable changes in highly vulnerable systems *(new emphasis)*; and the special and urgent need to develop protection and adaptation measures for tropical coral reefs *(maintained emphasis).*

Models and other considerations also suggest that a more focused set of indicators would be helpful for monitoring progress towards such a target. For example, trends and projections of sea surface temperatures, ocean acidity, coral reef bleaching events, proxies of marine nutrient loading in coral reef areas, etc. are readily available from observations and models and may be much better adapted to monitoring progress towards a component focusing on tropical coral reefs than very broad indicators of ocean health or human impacts on marine ecosystems.

4.6.2.5 Protected Areas and other Effective Area-based Measures (Target 11)

"By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved [...]"

While the world may be on track to meet or exceed the numeric target of protecting globally 17% of the land and 10% of the oceans by 2020 (Chapter 3), other aspects of the target, including the global connectivity and representativity of protected areas, and their coverage of areas important for biodiversity (including Key Biodiversity Areas), have made little or no progress (Butchart *et al.*, 2015; Santini *et al.*, 2016). These aspects may be more important that numeric targets per se, as demonstrated by the evidence that if new protected areas between 2004 and 2014 had targeted unrepresented threatened vertebrates, it would have been possible to protect >30 times more threatened species for the same area or cost as the actual expansion that occurred (Venter *et al.*, 2014).

In theory, it would be possible to hit much larger numeric targets for protected areas in the future. Depending on scenarios, between 30-40% of the land would remain primary (forest or non-forest) habitat in 2050, and artificial land-use types (urban, cropland and pasture) would occupy 30-40% of the land (Hurtt *et al.*, 2011). In practice, much land is already degraded by processes that can spread globally including climate change and invasive species, thus restoration will be required in addition to protection (IPBES, 2018a).

The uneven distribution of biodiversity (Butchart *et al.*, 2015), projected expansion of human population, and regional differences in projected land-use change (Hurtt *et al.*, 2011) suggest that global percentage targets do not necessarily achieve effective biodiversity conservation. Indeed, an analysis looking at Target 11 for 2020 (Visconti *et al.*, 2015) showed that expanding protected areas to protect 17% of the land while minimizing the opportunity cost for people (i.e. by prioritizing protection of unpopulated areas) would reduce habitat available to threatened mammals. The reason is that threatened mammals occupy areas densely populated by humans, and protecting unpopulated areas displaces further land conversion in highly populated areas. In addition, climate change may change dramatically the suitability of protected areas for their native biodiversity in the future (Hole *et al.*, 2009; Loarie *et al.*, 2009). Therefore, dynamic scheduling (Wilson *et al.*, 2007) based on scenarios of climate and land-use change and allowing species to move across landscapes to track suitable habitat and climatic space should be used to translate numeric targets into allocation of protected areas in space and time (Pressey *et al.*, 2007).

4.6.2.6 Preventing Extinctions and Improving Species Conservation Status (Target 12)

"By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained."

Forecasts of species decline are blurred by several sources of uncertainty. While scenarios exist for climate change and land-use change (which can be used to derive habitat loss), for other direct drivers of species loss, including invasive species, overexploitation, disease spread, scenarios are lacking. These drivers and their impacts start being projected into the future though rarely at global scale and with wide coverage of species biodiversity, but they will interact with or add up to land use and climate change, intensifying species declines. Interactions among drivers have only partly been explored (e.g., climate and land-use change; Mantyka-Pringle *et al.*, 2015). Even projections based on the same driver can differ widely. For example, the proportion of species that is projected to go extinct based on climate change varies with model assumptions (amount of extinction debt, species' ability to disperse) and modelling technique (species-area curves: 22% extinctions; mechanistic or correlative models: 6-8% extinctions) (Urban, 2015). Uncertainty on the species' response to global change (adaptation / plasticity, dispersal, or local extinction) is also reflected in uncertainty in the scenario outcome (Rondinini & Visconti, 2015). Finally, extinctions are fundamentally stochastic events caused by extinction vortexes (Soulé, 1986), which are difficult to predict and prevent.

Despite wide uncertainty in the projections, business-as-usual scenarios produce substantially different outcomes compared to scenarios having a strong focus on sustainability typically (Alkemade *et al.*, 2009; Newbold *et al.*, 2015; Visconti *et al.*, 2016). Assuming that species can cope with climate change, sustainability scenarios can almost halt their decline due to land-use change (Rondinini & Visconti, 2015). This, in addition to the evidence that conservation action alone is insufficient (Butchart *et al.*, 2010; Hoffmann & Sgrò, 2011; Tittensor *et al.*, 2014) suggests that halting biodiversity loss for some indicators such as population size or average conservation status is within the boundaries of scenarios, provided that a mixed strategy of stepped up conservation action and societal changes is adopted. However, the stochasticity of extinctions means that even in the best-case scenario, considering the current depauperate state of biodiversity, some extinctions may still occur.

4.6.2.7 Ecosystem Restoration and Resilience (Target 15)

"By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through [,,,] restoration of at least 15 per cent of degraded ecosystems [...]"

The main issue with quantifying degradation and restoration is the lack of a clear baseline (IPBES 2018e). Several possible baselines can be chosen as a reference for restoring degraded land, including pre-modern (<10,000 years BCE), historical (typically between 300 and 50 years ago), counterfactual (how an ecosystem would look like in the absence of human pressures). For this reason, the scientific community has not been able to provide a detailed global assessment of land degradation, and different models estimate the proportion of degraded land between 7-40% (Gibbs & Salmon, 2015; Van der Esch *et al.*, 2017).

Given the uncertainty in the quantification of current land degradation, scenario analysis cannot provide strong quantitative predictions around restoration, but boundaries for restoration opportunities can be identified. According to the World Resource Institute, over 20 million km^2 of degraded tropical and temperate forests would be suitable for restoration (Laestadius *et al.*, 2011). Extending afforestation further, to non-forest biomes, would have significant negative effects on ecosystem services (Veldman *et al.*, 2015) as well as inevitably on the biodiversity adapted to these biomes. A trade-off between restoration of natural ecosystems and bioenergy production exists, since under a business-as-usual scenario, limiting warming to 2° C will require an expansion of bioenergy production to abandoned and degraded land (Dauber *et al.*, 2012; Nijsen *et al.*, 2012) to achieve negative emissions from biofuels (van Vuuren *et al.*, 2011).

4.7 DEALING WITH UNCERTAINTY, SPATIAL SCALE AND TEMPORAL SCALE ISSUES WHEN MOBILIZING SCENARIOS AND MODELS FOR DECISION-MAKING

4.7.1 Scenarios and models help prepare decision makers for uncertainty and long-term thinking

In the IPBES methodological assessment of scenarios and models, Ferrier *et al.* (2016) provide several examples of the use of scenarios and models in support of decision-making and policy. The methodological assessment highlights, in particular, the importance of matching the spatial and temporal scales of scenarios and models to the needs of the specific policy and decision context, and of identifying sources of uncertainty, communicating uncertainty in a transparent way to decision makers and providing tools to deal with uncertainty.

When these issues are dealt with appropriately, scenarios and models can help people prepare for future uncertainty, promote long-term thinking and broaden perspectives. For example, Johnson *et al.* (2016) found that reading scenarios of future land-use changes increased the willingness of a wide range of stakeholders to participate in land-use planning. Scenarios and models have also proven to be effective tools for engaging indigenous and local knowledge holders in planning management of socio-ecological systems (Ferrier *et al.*, 2016; Hartman *et al.*, 2016; Oteros-Rozas *et al.*, 2015). Ground truthing through monitoring, especially with engagement of stakeholders, is a valuable approach for reducing uncertainties (Robinson *et al.*, 2017). **Box 4.7.1** provides examples of the use of scenarios and models in support of decision-making, with a focus on the role of uncertainty and scale.

Box 4 7 1 **Case studies of uncertainty and scale in decision-making using models and scenarios.**

Example 1: Forest management and climate change – Forest managers are very actively using scenarios and models to develop management strategies for dealing with climate change because tree growth is very sensitive to climate and because trees generally live a long time, often more than a century, before they are harvested (Keenan, 2015). Forest managers often desire very fine spatial resolution climate projections (ca. 1 km^2) in order to make site-based management decisions, and the climate modeling community has made tremendous efforts to downscale global scale climate projections in order to meet this type of demand from a wide range of stakeholders (Giorgi *et al.*, 2009). However, downscaling introduces new sources of uncertainty that can degrade the quality of climate projections (Stefanon *et al.*, 2015) and often contribute little to improving management strategies (Keenan, 2015). Forest managers are also often presented with projections of climate impacts on trees and forests based on a single type of impact model. However, several model inter-comparisons show that different types of models – for example, correlative and mechanistic models – often give very contrasting projections of tree growth and distributions in response to future climate change (Cheaib *et al.*, 2012). High uncertainty in future global climate projections, high uncertainty in modeling impacts on trees and uncertainties introduced when downscaling climate projections have left many forest managers in a quandary about how to plan for climate change. Current recommendations focus on managing for uncertainty by employing forest management schemes that are robust under a broad range of climate and impact projections, for example by increasing resilience, by managing for higher genetic and species diversity, or by promoting natural regeneration (Cheaib *et al.*, 2012; Keenan, 2015). More importantly, there is a growing recognition that adaptive strategies for dealing with an uncertain future must be developed much more inclusively by creating partnerships between researchers from multiple disciplines, forest managers and local actors including indigenous communities in many cases (Keenan, 2015).

Example 2: Climate change and biodiversity at national and regional scales – The PARCC West Africa Project (Belle *et al.*, 2016) conducted a biodiversity risk and adaptation assessment using a combination of IPCC AR5 global scale climate projections, together with finer scaled assessments driven by higher resolution climate downscaling for five focal countries. While uncertainty in temperature projections was reduced through confirming consensus between local and global model projections, uncertainty in rainfall projections remained high in many areas, even though only one general circulation model was applied. A representative range of scenarios was used to assess risks to biodiversity especially in the context of protected area networks, and from this to design adaptation strategies and build regional capacity to enhance implementation. Multi-country efforts were integrated from local to regional scales to develop policy recommendations for climate change adaptation and management at national and regional levels.

Example 3: Participatory scenarios at local scales – Oteros-Rozas *et al.* (2015) reviewed 23 case studies of place-based participatory scenarios to assess the characteristics, strengths and weaknesses of participatory modeling. All but one study involved local communities, most included members of local governments and sixteen involved indigenous communities. Qualitative storylines in the form of drawings, or illustrations were the most common output (Figure 1), but most participatory processes also produced reports and scientific publications. Local communities were the most common primary audience, and fifteen studies had the explicit objective of informing policy or decision-making. Uncertainty was examined in sixteen of the studies, most focusing on uncertainty in drivers. Only six studies explicitly accounted for drivers or impacts at spatial scales above the local scale under consideration. The authors concluded that well-designed participatory processes enriched both local environmental management and scientific research by generating shared understanding and fostered thinking about future planning of social-ecological systems. Unfortunately, in most cases there was insufficient follow-up to determine the contribution to long-term policy or management outcomes. Numerous additional examples can also be found at the consortium of 'companion modeling' (www.commod.org).

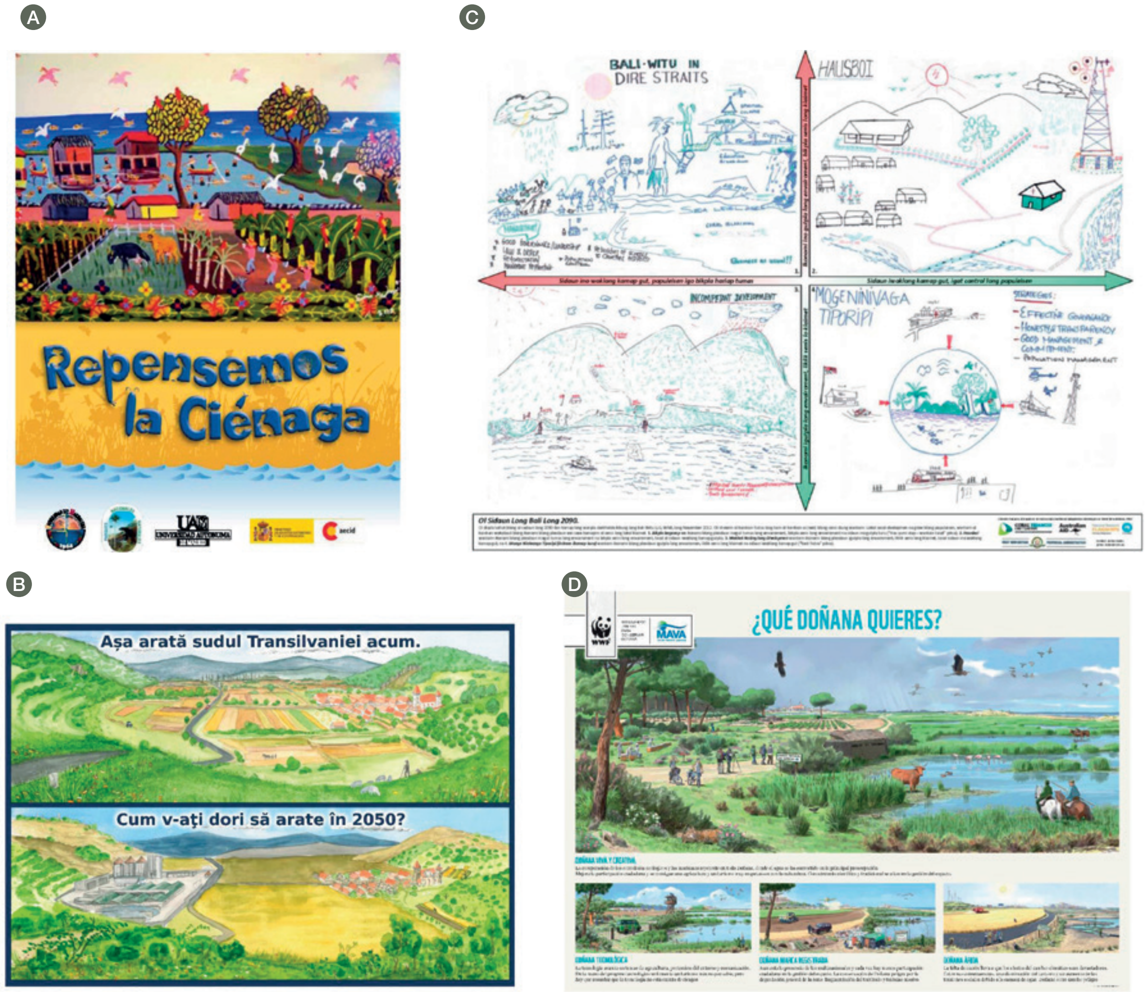


Figure 1 **Examples of outreach material used for communicating scenarios results:**

A leaflet of the Ciénaga Grande of Santa Maria case in Columbia; B postcard of the Southern Transylvania case in Romania; C poster of the drawing of the four scenarios of the Papua New Guinea case; and D poster of the socio-ecological system of Doñana Protected Area case in Spain (from Oteros-Rozas *et al.*, 2015).

4.7.2 Dealing with uncertainty when using scenarios and models to support decision-making

Uncertainty in scenarios and models arises from many sources including insufficient data for development and testing, inadequate representation of complex socio-ecological systems and intrinsically low predictability of the system being analyzed (Ferrier *et al.*, 2016). The importance of these sources of uncertainty differs greatly between scenarios of direct and indirect drivers and models of impacts on nature and NCP (Brotons *et al.*, 2016; Ferrier *et al.*, 2016). As noted in the introduction of this chapter, the exploratory scenarios assessed in this chapter can help address the high level of uncertainty in many components of direct and indirect drivers by exploring a wide range of plausible futures (Pichs-Madruga *et al.*, 2016). Evaluation of uncertainty in models of nature and NCP are typically addressed using comparisons of model outputs with data, intercomparisons of multiple types of models, sensitivity analyses and measures of error propagation in coupled models (Brotons *et al.*, 2016).

Uncertainty in scenarios and model projections is not necessarily a major obstacle to acceptance by stakeholders, especially if it does not directly conflict with their recent experiences (Kuhn & Sniezek, 1996). Indeed, despite the common perception that communication of uncertainty can lead to confusion for decision makers, recent studies show that most audiences value the communication of uncertainty in scientific evidence as opposed to oversimplification (Fischhoff & Davis, 2014; Rudiak-Gould, 2014). This highlights the importance of transparency as well as sustained, effective communication between scientists and decision makers throughout the processes of using models for decision support (Acosta *et al.*, 2016; Ferrier *et al.*, 2016). There are also a wide range of qualitative and quantitative decision support mechanisms that can help decision makers deal with uncertainty, even though these tools are underexploited in many decision-making contexts (Acosta *et al.*, 2016).

The literature survey carried out for this chapter (Appendix A4.1.1) highlights the challenges facing the scientific community in dealing with uncertainty. The majority of studies did not include an analysis of uncertainty **(Figure 4.7.2a)**. Of those that did include an analysis, most focused on uncertainty associated with different scenarios of direct and indirect drivers and less than half provided quantitative analyses of uncertainty. Relatively few studies examined multiple sources of uncertainty. This analysis shows that significant progress needs to be made in understanding, quantifying and communicating uncertainty in order for scenarios and models to be more widely used in decision-making.

In the small number of studies that have assessed uncertainty across a wide range of sources, the relative contribution of sources of uncertainty varies substantially over time, space and different measures of nature or NCP (e.g., **Figure 4.7.2b**; Payne *et al.*, 2016). These analyses also indicate that currently the largest sources of uncertainty arise from differences in model structure or application rather than data, scenarios or models of direct drivers (e.g., **Figure 4.7.2b**; Payne *et al.*, 2016). It is important to note as well that the range of scenarios typically used in many analyses may not cover plausible extremes and potential regime shifts (Leadley *et al.*, 2010; Pereira *et al.*, 2010; Prestele *et al.*, 2016).

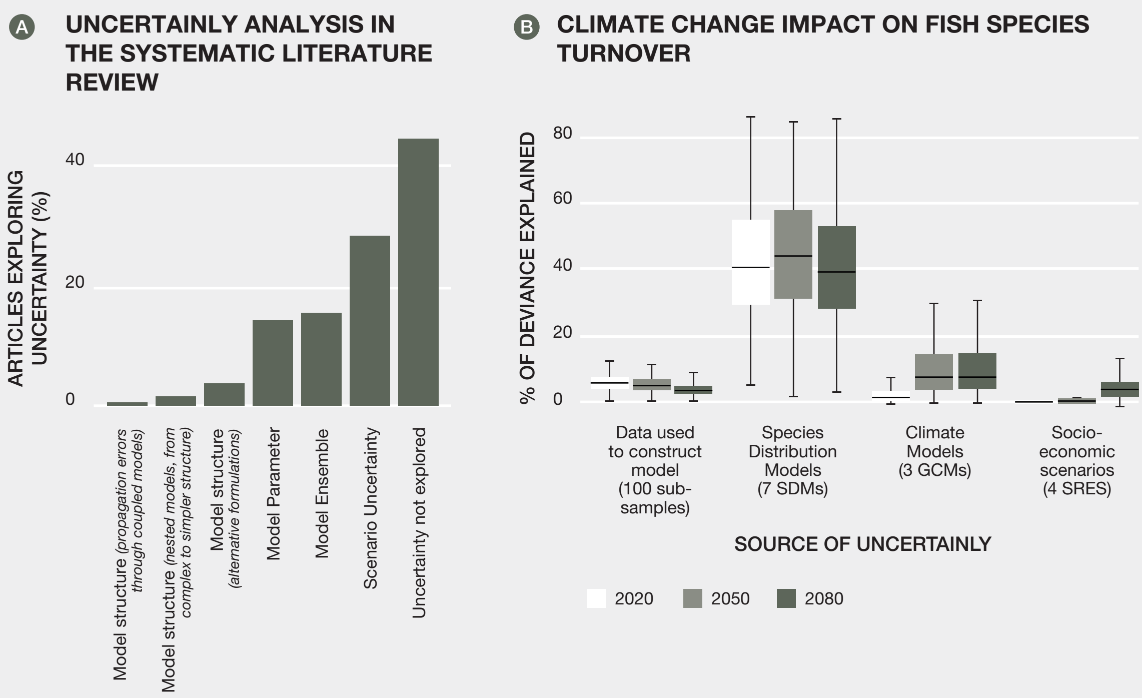


Figure 4 7 2 **Treatment and importance of different sources of uncertainty in models and scenarios of nature and NCP.**

A Outcome of the analysis of the systematic literature review (Appendix A4.1.1) showing the percentage of studies that include estimates of different sources of uncertainty. B An example of systematic analysis of sources of uncertainty in models of fish community responses to climate change (from Buisson *et al.*, 2010).

Comparisons of models and observations provide a powerful means of evaluating uncertainty in models of impacts on nature and NCP, and for communicating with decision makers. Considerable work has been done to evaluate models of ecosystem functions and some categories of NCP (e.g., ecosystem carbon stocks and fluxes; Zaehle, 2013), that indicated large variation between models, and helped improving the understanding of the capacities and limits of these models. On the other hand, models of global change impacts on species diversity, species range, habitat change and many NCP suffer from a chronic deficit of comparison with independent datasets (i.e., datasets that are entirely independent from the data used to develop and calibrate the model (Araújo & Guisan, 2006; Settele *et al.*, 2014). Those studies that have made robust comparisons between models and data indicate that agreement between models and data varies greatly between species, habitats and NCP (Araujo & Rahbek, 2006; Sitch *et al.*, 2008). It is widely acknowledged that significant progress needs to be made in comparing models and data in order for scenarios and models to be more widely used in decision-making (Araújo & Guisan, 2006; Dawson *et al.*, 2011).

There is a growing consensus that triangulation of multiple approaches, e.g., ecosystem and species models, projections based on trend extrapolation, in situ observations and experimentation, should be used to increase confidence in models (Dawson *et al.*, 2011). There are a number of efforts underway to improve international collaboration to including efforts being supported by IPBES (Rosa *et al.*, 2017; Tittensor *et al.*, 2018b).

4.7.3 The challenge of spatial and temporal scales in using scenarios and models to support decision-making

The IPBES conceptual framework emphasizes the importance of considering multiple temporal and spatial scales (e.g. local, national, regional and global scales) in understanding, assessing and managing nature and nature's contributions to people (Diaz et al 2015a, b) note that "although the biodiversity crisis is global, biodiversity distribution and its conservation status is heterogeneous across the planet; therefore, the solutions will have to be scalable to a much finer level". As such, scenarios and models used for assessments and decision support need to be developed at a wide range of spatial and temporal scales and relationships between scales need to be explicitly accounted for (Ferrier *et al.*, 2016; Rosa *et al.*, 2017).

The IPBES methodological assessment of scenarios and models highlighted the strong relationships between spatial and temporal scales, types of scenarios employed and decision-making contexts (Ferrier *et al.*, 2016; **Figure 4.7.3**). Participation of stakeholders in developing scenarios is more common and better formalized at the local scale than at regional or global ones. Local scale scenarios and models also often focus on projections over much shorter time horizons, several years to a few decades, whereas supra-national scenarios and models are often multi-decadal (Ferrier *et al.*, 2016). Local policy and decision-making more often mobilize intervention scenarios to examine policy design and implementation with the objective of providing input to decision support. At the other end of the spectrum of spatial scales, global policy and decision-making tend to rely on exploratory scenarios for agenda setting or policy review **(Figure 4.7.3)**. These relationships between spatial and temporal scale with their use within different parts of the policy cycle are important to keep in mind as a context for interpreting the analyses presented earlier in this chapter.

Explicitly accounting for linkages across spatial and temporal scales can, in some decision contexts, enhance the ability of existing scenarios and models to address the multi-scale nature of environmental policy and decision-making (Cheung *et al.*, 2016; Rosa *et al.*, 2017). For example, studies undertaken at larger scales lose the site specificity that policymakers and managers often desire. On the other hand, local case studies provide a refined understanding of local issues based on long term investigation at specific locations, but the possibility of generalizing findings is limited by the geographic coverage of the studies and the locality-specific conditions (Castella *et al.*, 2007). These are common and well-known trade-offs among precision, realism and generality one faces when constructing and analyzing models (Levins, 1966).

Existing scenarios and modeling tools and approaches typically do not capture, or poorly capture the linkages across scales, including interactions and feedbacks between them (Carpenter *et al.*, 2009; Cheung *et al.*, 2016). This is in large part due to methodological limitations that are difficult to overcome, although ambitious efforts are now addressing solutions (e.g., Purves *et al.*, 2013). The IPBES methodological assessment report on scenarios and models of biodiversity and ecosystem services explored how to address societal and ecological processes that act at multiple spatial scales, and the challenges they present for decision-making (Cheung *et al.*, 2016). Multi-scale processes can be forecasted by linking (coupling) across scales, scenarios and models developed at particular scales. This process often requires some harmonization of scenarios across spatial scales.

Harmonization across spatial scales involves upscaling (summarizing fine-scale information at coarser scale) and/or downscaling (inferring fine-scale information from coarser scale). Existing applications have greater emphasis on downscaling than upscaling. Downscaling provides information for local-scale policy making using the large

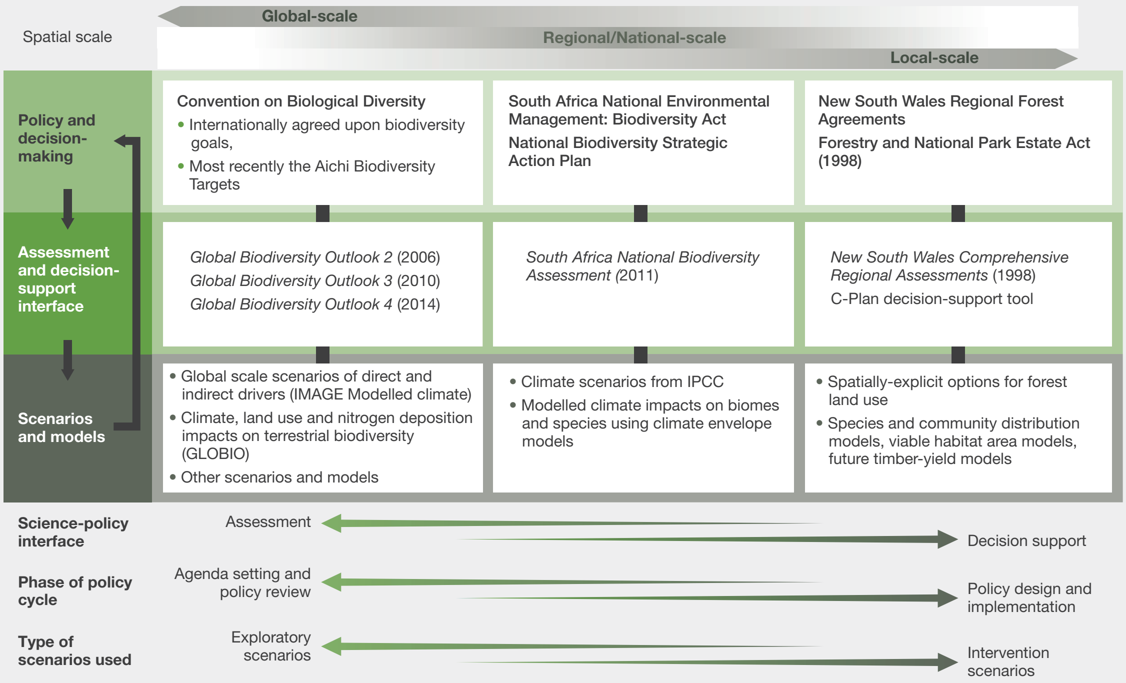


Figure 4 7 3 **Examples of the use of scenarios and models in agenda-setting, policy design and policy implementation relating to the achievement of biodiversity targets across a range of spatial scales.**

The diagram indicates the typical relationships between spatial scale (top arrows), type of science-policy interface (upper set of arrows at bottom), phase of the policy cycle (middle set of arrows at bottom) and type of scenarios used (lower set of arrows at bottom). Source: IPBES (2016b).

scale information and projections as boundary conditions and using the most refined local information to represent local processes more reliably. However, while the objective is to decrease process uncertainty at the local scale, the change of scale can introduce new sources of uncertainty, because downscaling is usually done through modelling or heuristic rules that introduce errors. Models and scenario comparison across multiple sites is another means to upscale scenarios and infer generalities, and there is a growing number of applications of this approach: Fish-Mip (Tittensor *et al.*, 2018b); IndiSeas (Fu *et al.*, 2018; Shin *et al.*, 2018); Madingley Model (Bartlett *et al.*, 2016; Harfoot *et al.*, 2014). Technical progress is being made in downscaling and upscaling, in particular by integrating data from a wide variety of sources and using powerful mathematical tools that combine spatial interpolation, upscaling, downscaling, data fusion, and data assimilation (Hoskins *et al.*, 2016; Yue *et al.*, 2016).

Despite these methodological challenges, there are substantial potential benefits of using multi-scale scenarios and models for improving understanding of system dynamics and for providing better support for decision-making. Ferrier *et al.* (2016) recommend that the scientific community works "on methods for linking […] scenarios and models across spatial and temporal scales" and in particular that IPBES works with the scientific community to "develop a flexible and adaptable suite of multi-scaled scenarios" (see also Rosa *et al.*, 2017). Approaches for developing multi-scale scenarios include using global-scale scenarios as boundary conditions for regional-scale scenarios, translating global-scale storylines into regional storylines, using standardized scenario families to independently develop scenarios across scales, and the direct use of global scenarios for regional policy contexts. These methods of upscaling can minimize inconsistencies between local scale contexts with larger scale assumptions, while also representing a diversity of local scale contexts (see Biggs *et al.*, 2007 for an example). However, substantial resources and effort are needed to coordinate the development and aggregation of multiple local scale scenarios, so it is rarely done. Of particular importance, is the post-hoc approach to scaling used in Chapter 5 of this assessment and the IPBES regional assessments that have used common (or "archetype") scenarios in order to make qualitative linkages across spatial and temporal scales (see also Biggs *et al.*, 2007; Kok & van Delden, 2009).

However, multi-scale scenarios and models are not appropriate in every decision context, particularly when error propagation increases uncertainty to an unacceptable level. When system processes interact across scales resulting

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in nonlinear dynamics, harmonizing of models and their outputs across these scales is more prone to scaling error, therefore the uncertainty resulting from model linkages should be quantified (Cheung *et al.*, 2016), but the literature survey suggests this is rarely done (see section 4.7.2).

4.7.4 Improving communication and building capacity to enhance the use of scenarios and models in decision-making

The IPBES methodological assessment of scenarios and models highlighted cases in which scenarios and models have been successfully mobilized for policy and decision-making (Ferrier *et al.*, 2016). It also, however, identified several key factors that have limited the mobilization of scenarios and models for policy and decision-making (Acosta *et al.*, 2016). Many of these factors are related to insufficient communication between scientists and decision makers and the willingness and capacity of scientists and decision makers to engage in long-term interactions but may also run into more fundamental problems such as complex political agendas that are not compatible with the transparency associated with good scientific practice (Acosta *et al.*, 2016).

The IPBES methodological assessment of scenarios and models made several recommendations for improving the use of scenarios and models in decision-making to address these deficiencies (Ferrier *et al.*, 2016). One of the most important keys is to establish and maintain interactions between policymakers, stakeholders and scientists (see also Fiske & Dupree, 2014; Scheufele, 2014). In most successful applications, this typically involves many cycles of feedback between these groups during the development and use of scenarios and models. Sustained interactions between these groups help ensure that a relationship of trust is built between modelers and decision makers, that scenarios and models are adapted to the decision-making context, and that all parties understand the capacities and limits of scenarios and models.

Human and technical capacity for scenario development and modeling needs to be enhanced in order to address these shortcomings (Lundquist *et al.*, 2016). Recommendations for capacity building include promoting of open and transparent access to scenario and modelling tools, to data required for the development and testing, and to training programs on scenarios and models for scientists and stakeholders (Biggs *et al.*, 2018; Lundquist *et al.*, 2016).

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Chapter 5.

PATHWAYS TOWARDS A SUSTAINABLE FUTURE

IPBES GLOBAL ASSESSMENT REPORT ON BIODIVERSITY AND ECOSYSTEM SERVICES
CHAPTER 5. PATHWAYS TOWARDS A SUSTAINABLE FUTURE

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CHAPTER **5**

PATHWAYS TOWARDS A SUSTAINABLE FUTURE

EXECUTIVE SUMMARY

Current evaluations (chapters 2, 3) and most future scenarios (chapter 4) show that goals for conserving and sustainably using nature and achieving sustainability cannot be met by current trajectories, and goals for 2030 and beyond, the 2020 Aichi Biodiversity Targets, and Paris Agreement on Climate Change may only be achieved through transformative changes across economic, social, political and technological factors. This chapter examines pathways towards successfully achieving these overarching goals. Our purpose is to distil from these and broader literatures the key elements of sustainable pathways—that is, ones that at a minimum would achieve the global goals related to nature by 2050 or earlier.

This analysis was rooted in the existing scenario literature mainly at the global scale incorporating results from IPBES' regional assessments, focusing on target-seeking scenarios, sustainability-oriented exploratory scenarios, and selected policy-screening scenarios. From this scenario review and our syntheses of broader literatures related to multiple drivers and complex human-nature dynamics, we analyse interactions between multiple sectors and objectives through a **nexus approach**—that is considering interactions between diverse goals and sectors. We apply this approach via six complementary foci for achieving clusters of SDGs. This analysis revealed synergies, trade-offs and common key elements in the simultaneous achievement of clusters of SDGs, incorporating thinking across scales, domains, sectors and disciplines. Below are key findings pertaining to these.

1 **The pathways to achieve global goals related to nature vary significantly across geographic contexts, with different changes needed to achieve them at all scales (e.g., local, national, regional and international) (*well established*).** Sustainable pathways are flexible, within a range. These pathways imply major deviations from current trends and indicate the need for sustained efforts over decades to meet internationally-agreed objectives. Despite the diversity, there is much commonality across these pathways and the interventions to achieve them {5.1. 5.2.2 and 5.3}.

2 **The first focus of our nexus approach is the challenge of feeding humanity while enhancing the conservation and sustainable use of nature (SDG 15, also considering 2, 12). Our analysis concludes that future agricultural systems could feed humanity and conserve biodiversity inclusively and equitably. Such pathways imply transformation of production (e.g., broad adoption of region-specific agroecological approaches and cross-sectoral integrated landscape and watershed management), supply chains (e.g., responsible trade, phasing out harmful subsidies), and demand sides of food systems (e.g., waste reduction, diet change) (*well established*) {5.4.2.1}.** Competing uses for land, e.g., for land-based climate mitigation through bioenergy production, only exacerbate these needs {5.4.2.2}. (a) Related to **agricultural production**, the diversity of agricultural systems, from small to industrial-scale, create opportunities and challenges for transformation to sustainability. The uniformity at the heart of many agricultural systems—particularly at industrial scales—and their reliance on chemical fertilizers, pesticides and preventive use of antibiotics, triggers negative outcomes and vulnerabilities. However, across these different systems, pathways to sustainable production are emerging guided for instance by agroecological principles, landscape planning, and sustainable intensification technologies. These practices could be enhanced through well-structured regulations, incentives and subsidies, and the removal of distorting subsidies. (b) Related to **supply chains**, a few food companies are in positions of power to influence positive changes at both production and consumption ends of supply chains (such as standards, certification and moratorium agreements). This creates opportunities but also risks of co-option and inaction, which can be addressed through regulations and global governance mechanisms to check or override commercial interests in maintaining monopolies and the status quo. The same applies to agricultural input companies regarding restrictions on pesticides and chemical fertilizers considered harmful to human health and the environment. (c) Finally, **end consumers** have the potential to influence the supply chain and agricultural production through their purchases and activism, via certification and pressure on brands for transparency and particular practices {5.3.2.1}.

3 **The second focus is meeting climate goals while maintaining and restoring nature and its contributions to people (SDGs 7 and 13, also considering 2 and 15). In order to meet substantial climate mitigation objectives (such as the Paris Agreement's 'well below' 2°C target), a major escalation of dedicated bioenergy plantations has been proposed, but due to its large land area, this is unlikely to be compatible with biodiversity targets (*well established*). Nevertheless, a combination of other land-based mitigation activities, such as nature restoration and improved land management, have large potential for climate mitigation with positive effects on nature and its contributions to a good quality of life, including, food and water security (*established but incomplete*).** Bioenergy systems can also positively affect biodiversity, carbon storage and other ecosystem services. Economic incentives might be carefully designed to promote those bioenergy systems that minimize biodiversity losses and deliver multiple benefits. However, demand-side climate mitigation measures (e.g., reduced food waste or demand for energy and livestock products) can often be more successful in achieving multiple goals, such as greenhouse gas emission reduction, food security and biodiversity protection than bioenergy plantations. These actions imply a gradient of change in consumption and lifestyles, some of which pose challenges. {5.4.1.1, 5.3.2.2}.

4 **The third focus is achieving nature conservation and restoration on land while contributing positively to human well-being (SDG 15, also considering 3). Expansion of current protected area networks—and making them ecologically effective, representative and well-connected—is central to successful pathways (*well established*). However, to accommodate conservation and restoration where land is an increasingly limited resource, extensive and proactive participatory landscape-scale spatial planning is key (*well established*).** The scenarios literatures, especially at local to national scales, point out ways to further safeguard protected areas into the future, including enhancing monitoring and enforcement systems, managing biodiversity-rich land and sea beyond protected areas, addressing property rights conflicts and protecting environmental legal frameworks against the pressure of powerful interest groups (agribusiness, mining, and infrastructure). Facilitating and scaling up financing mechanisms to promote restoration and conservation within and outside protected areas are critically important, particularly in developing regions. In many areas, conservation will require building capacity and new forms of stakeholder collaboration, and removing existing barriers (e.g., unresolved land tenure, land/sea access, harmful economic incentives and policies, etc.). Also important are economic alternatives, technical assistance, well-designed payment for ecosystem services (PES) programs {5.4.2.1}, new value chains for local agricultural and biodiversity products, and better access to basic services (education, health, etc.). Indigenous Peoples and Local Communities (IPLCs) are central players, as at least one quarter of the global land area is traditionally managed, owned, used or occupied by Indigenous Peoples[1]. These areas include approximately 35 per cent of the area that is formally protected, and approximately 35 per cent of all remaining terrestrial areas with very low human intervention. Finally, well-designed innovations for the conservation-oriented economic use of biodiversity (e.g., biomimicry in pharmaceuticals, cosmetics, food) could foster conservation while benefiting local populations and regional economies {5.3.2.3}.

5 **The fourth focus is maintaining freshwater for nature and humanity (SDG 6, also considering 2 and 12). Pathways exist that improve water use efficiency, increase storage and improve water quality while minimising disruption of natural flow regimes. Promising interventions include practising integrated water resource management and landscape planning across scales; protecting wetland biodiversity areas; guiding and limiting the expansion of unsustainable agriculture and mining; slowing and reversing de-vegetation of catchments; and mainstreaming practices that reduce erosion, sedimentation and pollution run-off and that minimize the negative impact of dams (*well established*).** Major interventions enable achievement of these SDGs, differing across contexts. Key among these are three general changes: (a) improving freshwater management, protection and connectivity; (b) participation of a diversity of stakeholders, including Indigenous Peoples and Local Communities, in planning and management of water and land use (including protected areas and fisheries); and (c) strengthening and improving implementation and enforcement of environmental laws, regulations, and standards. Slowing and reversing deforestation of catchments is key to buffering surface and underground storage, and maintaining sediment transport regimes and water quality. Sector-specific interventions include improved water-use efficiency techniques (including in **agriculture, mining and energy)**. Freshwater biodiversity goals can be facilitated by **energy** production interventions, including scaling-up non-hydro renewable energy generation (wind, solar), transitioning to air and sea-water cooling, and judicious evaluation of hydropower developments. Increased **water storage** can be achieved through policies that implement a mix of groundwater recharge, integrated management (e.g., 'conjunctive use') of surface and groundwater, wetland conservation, low-impact

1. These data sources define land management here as the process of determining the use, development and care of land resources in a manner that fulfils material and non-material cultural needs, including livelihood activities such as hunting, fishing, gathering, resource harvesting, pastoralism, and small-scale agriculture and horticulture.

dams, decentralized (for example, household-based) rainwater collection, and locally developed water conservation techniques (such as those developed by Indigenous Peoples and Local Communities) and water pricing and incentive programmes (such as water accounts and payment for ecosystem services programmes). Balancing competing human and environmental demands for water entails improved recognition of the different values of the resource (e.g., via water accounts, payment for ecosystem services programs, etc.), and improved governance systems inclusive of diverse stakeholders. Pricing policies that respect the human right to safe drinking water are important to manage **water consumption and reduce waste and pollution**. Further investments in infrastructure are important, especially in developing countries, undertaken in a way that considers ecological function and the careful blending of built with natural infrastructure {5.3.2.4}.

6 **The fifth focus is harmonizing food provision and biodiversity protection in the oceans (SDG 14, also considering 2, 12). Successful pathways include the effective implementation and expansion of marine protected areas and ecosystem-based fisheries management, with spatial planning and targeted restrictions on catches or fishing effort (*well established*).** Achieving biodiversity and food security goals in marine ecosystems will involve close attention to their synergies and trade-offs. In particular, safeguarding and improving the status of biodiversity will often entail reducing the negative effects of fish harvest and aquaculture, potentially resulting in near-term losses in access to living marine resources. There is also complementarity between biodiversity and food provision, however meeting food security goals will often involve promoting the conservation and/or restoration of marine ecosystems including through rebuilding overfished stocks; preventing, deterring and eliminating illegal, unreported and unregulated fishing; encouraging ecosystem-based fisheries management; and controlling pollution through removal of derelict gear and addressing plastics. Some of the trade-offs between food provision and biodiversity projection can be managed or avoided through appropriate social participation and community engagement in decision-making and implementation. Sustainable pathways also entail addressing growing problems with many marine pollutants—particularly those prone to bioaccumulation—which both affect marine ecosystems and undermine seafood safety and human health. Similarly, attaining sustainable pathways will be more feasible given stronger greenhouse gas reductions, which should lessen trade-offs between biodiversity and food provision. Thus, pathways to sustainable ocean development involve addressing multiple human stressors {5.3.2.5}.

7 **The sixth focus is sustaining cities while maintaining the underpinning ecosystems (both local and regional) and their biodiversity (SDG 11, also 15). Successful pathways generally entail integrated city-specific and landscape-level planning for retaining species and ecosystem in cities and surrounding regions, as well as limits on urban transformation. These can be achieved by strengthening local- and landscape-level governance and enabling transdisciplinary planning to bridge sectors and departments, and to engage businesses and other organizations in protecting public goods (*well established*).** Because many aspects of life within cities are underpinned by nature, achieving these goals is important not only for global biodiversity but also for local human quality of life. Opportunities to integrate ecological and built infrastructure are increasingly important, particularly for cities in developing countries with high deficits of infrastructure. Maintaining and designing for ecological connectivity within urban space is critical for nature and people, especially in large cities. Particularly important at the regional scale are policies and programmes that promote sustainability-minded collective action protect watersheds beyond city jurisdiction and ensure the connectivity of ecosystems and habitat (e.g., through green-belts), and that city expansion towards key regional biodiversity sites does not undermine their conservation mandates. Sustaining nature's contributions to people—for current and future needs—implies integrating these considerations into planning and development of infrastructure investments. Specifically, this includes encouraging—at all scales—compact communities, underlying road network designs, and sustainable transportation systems (including active, public and shared transport), which enable low-carbon and low-resource lifestyles throughout the decades or centuries over which this infrastructure will persist {5.3.2.6}.

8 **The cross-scale nexus analysis reinforced the importance of including regional and local perspectives in global pathways to sustainability.** Global scenarios alone do not capture some difficulties and unintended consequences of implementing certain measures at regional and local levels. Key constituents of regionally sensitive global pathways include (a) substantially bolstering monitoring and enforcement systems, which are especially weak in developing nations; and (b) enabling locally tailored choices about consumption and production, accounting for poverty, inequality and cultural variability.

9 **The analysis based on the nexus approach suggests several common constituents of sustainable pathways that contribute to the achievement of seven nature-based Sustainable Development Goals (SDGs 2, 3, 6, 11, 13, 14 and 15).** These key constituents include (a) safeguarding remaining natural habitats on land and sea by strengthening, consolidating, expanding and effectively

managing protected areas and their integration with surrounding land uses *(well established*), (b) undertaking large-scale restoration of degraded habitats (*well established*), and (c) integrating these activities with development through sustainable planning and management of landscapes and seascapes so that they contribute to meet human needs including food, fibre, water and energy security, while continually reducing pressure on natural habitats *(well established*) {5.3.3}.

10 These SDG outcomes can be achieved through complementary top-down and bottom-up action on eight priority points of intervention (leverage points) and employment of five governance mechanisms (levers) {5.3.3, 5.4} (Figure 5.1). Supplementing with additional analysis from social sciences and other literature on transformative change and human-nature relationships suggests that these leverage points and levers may be non-substitutably important. Leverage points can be engaged via a range of different mechanisms, including the five levers and more.

11 Five main interventions ("levers") can generate transformative change to address the indirect drivers that are the root causes of nature deterioration: (1) incentives and capacity-building; (2) cross-sectoral cooperation; (3) pre-emptive action; (4) decision-making in the context of resilience and uncertainty; and (5) environmental law and implementation. Employing these levers involves the following, in turn: (1) developing incentives and widespread capacity for environmental responsibility and eliminating perverse incentives; (2) reforming sectoral and segmented decision-making to promote integration across sectors and jurisdictions; (3) taking pre-emptive and precautionary actions in regulatory and management institutions and businesses to avoid, mitigate and remedy the deterioration of nature, and monitoring their outcomes; (4) managing for resilient social and ecological systems in the face of uncertainty and complexity to deliver decisions that are robust in a wide range of scenarios; and (5) strengthening environmental laws and policies and their implementation, and the rule of law more generally. All five levers may require

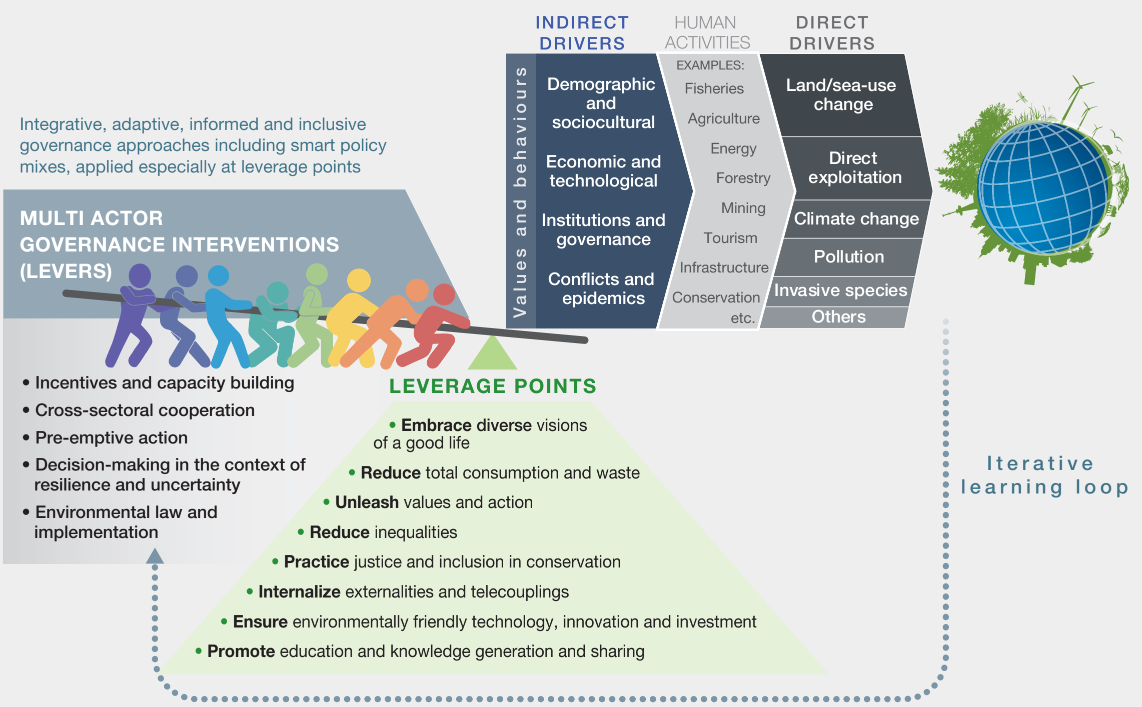

Figure 5 1 **Transformative change in global sustainability pathways.**

Collaborative implementation of priority governance interventions (levers) targeting key points of intervention (leverage points) could enable transformative change from current trends towards more sustainable ones. Most levers can be applied at multiple leverage points by a range of actors, such as intergovernmental organizations, governments, non-governmental organizations, citizen and community groups, Indigenous Peoples and Local Communities, donor agencies, science and educational organizations, and the private sector, depending on the context. Implementing existing and new instruments through place-based governance interventions that are integrative, informed, inclusive and adaptive, using strategic policy mixes and learning from feedback, could enable global transformation.

new resources, particularly in low-capacity contexts such as in many developing countries.

12 **The first two points of leverage are enabling visions of a good quality of life that do not entail ever-increasing material consumption (including due to population growth and waste), and lowering total consumption and waste, including by addressing both population growth and per capita consumption differently in different contexts.** Whereas the ability to increase consumption is key to improve human quality of life in some regions and countries, in more-developed contexts human quality of life can be enhanced with decreasing overconsumption and waste (*well established)* {5.4.1.1}. Such changes in consumption may be achieved by fostering existing alternative visions of a good quality of life (*well established)* {5.4.1.2}.

13 **The third leverage point is unleashing existing widely held values of responsibility to effect new social norms for sustainability, especially by extending notions of responsibility to include impacts associated with consumption.** Such norm changes require concerted effort but are feasible when infrastructure and institutions (including social arrangements, regulations and incentives) activate values held by individuals (*well established*) {5.4.1.3}. Diverse values are consistent with sustainable trajectories, but not all have received equal attention in global sustainability discourses.

14 **Leverage is also found in addressing inequalities, especially regarding income and gender, which undermine capacity for sustainability and ensuring inclusive decision-making, fair and equitable sharing of benefits arising from the use of and adherence to human rights in conservation decisions. Inequalities tend to reflect and can cause excessive use of resources (*established but incomplete*), and appropriate inclusion of Indigenous Peoples and Local Communities is central to justice and sustainable protection of nature (*well established)* {5.4.1.4, 5.4.1.5}.** Full and effective participation of Indigenous Peoples and Local Communities is important and would contribute to conservation, restoration and management of the extensive areas of land and water over which they retain rights or control (*well established*) {5.4.1.5}.

15 **Crucial but often-overlooked points of leverage are accounting for nature deterioration from local economic activities and socioeconomic-environmental interactions, including externalities, over distances (telecouplings) into public and private decision-making, such that technological and social innovation and investment regimes all work for—rather than against—nature and sustainability, taking into account potential rebound effects. These leverage points are central to a global sustainable economy.** Whereas existing environmental policies and international trade have often reduced negative impacts in a specific place, many have had unintended spillover effects elsewhere (*well established)* {5.4.1.6}. More important in this context than valuation is to actually reflect these costs in economic decision-making (via required payments for mitigating damages), which can be initiated by private or public actors. Similarly, technological innovations are ambivalent in their impact on biodiversity (*well established)* (5.4.1.7). Regulations and non-governmental governance mechanisms including standards and certification can ensure that innovation and investment have positive effects at the global scale, which is key to global sustainable economies and sustainable pathways (*well established)* {5.4.1.6 and 5.4.1.7}.

16 **Transformations towards sustainability are more likely when efforts are directed at the following key leverage points, where efforts yield exceptionally large effects (Figure SPM.9): (1) visions of a good life; (2) total consumption and waste; (3) values and action; (4) inequalities; (5) justice and inclusion in conservation; (6) externalities and telecouplings; (7) technology, innovation and investment; and (8) education and knowledge generation and sharing.** Specifically, the following changes are mutually reinforcing: (1) enabling visions of a good quality of life that do not entail ever-increasing material consumption; (2) lowering total consumption and waste, including by addressing both population growth and per capita consumption differently in different contexts; (3) unleashing existing widely held values of responsibility to effect new social norms for sustainability, especially by extending notions of responsibility to include impacts associated with consumption; (4) addressing inequalities, especially regarding income and gender, which undermine capacity for sustainability; (5) ensuring inclusive decision-making, fair and equitable sharing of benefits arising from the use of and adherence to human rights in conservation decisions; (6) accounting for nature deterioration from local economic activities and socioeconomic-environmental interactions over distances (telecouplings), including, for example, international trade; (7) ensuring environmentally friendly technological and social innovation, taking into account potential rebound effects and investment regimes; and (8) promoting education, knowledge generation and maintenance of different knowledge systems, including the sciences and indigenous and local knowledge regarding nature, conservation and its sustainable use.

17 **The eighth point of intervention is promoting education, knowledge generation and maintenance of different knowledge systems, including the sciences and indigenous and local knowledge regarding nature, conservation and its sustainable use. These elements**

are especially important in the face of demographic processes increasing the 'distance' between urbanizing populations and nature. Education generally only fosters changes in consumption, attitudes and relational values conducive to sustainability when it builds on existing understandings, enhances social learning, and embraces a "whole person" approach (*well established)* {5.4.1.8}. Whereas Indigenous Peoples and Local Communities have or had various traditional practices and/or norms that enabled sustainable use of local resources, communities worldwide are facing loss of knowledge transmission along with changes in values and lifestyles. Achieving sustainability from local to global levels will benefit from multiple strategies for education and learning, from recognizing and promoting local environmental knowledge and sustainable practices to integration throughout school curricula (*well established)* {5.4.1.5 and 5.4.1.8}.

18 **Applicable across many intervention points, the first lever is developing incentives and widespread capacity for environmental responsibility. Important actions would often include eliminating perverse subsidies and improving fairness in regulations and incentive programs at every scale (*well established*) {5.4.2.1}.** Whereas many incentive programs are designed in ways that may undermine stewardship and responsibility-taking (*well established)*, there appears to be great scope for subtle changes to policies and programs to instead reinforce commitment with such relational values (*established but incomplete)* {5.4.1.3 and 5.4.2.1}.

19 **Three levers pertain to management and governance institutions. These are reforming business and economic, political and community structures to enable decision-making that (2) promotes integration across sectors and jurisdictions, (3) takes pre-emptive and precautionary actions in regulatory and management institutions and businesses to avoid, mitigate and remedy the deterioration of nature, also monitoring these outcomes, and (4) manage for resilient social and ecological systems in the face of uncertainty and complexity to deliver decisions that are robust in a wide range of scenarios.** Whereas many resources are managed separately with only limited capacity to account for interactions between resources in social-ecological systems, management that integrates more fully across sectors and jurisdictions appears to be central to achieving global sustainability goals (*well established*) {5.4.2.2}. Most resource management and environmental assessment approaches are reactionary, generally enforcing regulations after damage occurs, rather than anticipating it, despite the latter being more suitable for sustainable trajectories (*well established*) {5.4.2.3}. Finally, achieving global goals entails avoiding undesirable collapses of resource systems and restoring underperforming degraded systems, both of which follow from governance for resilience and adaptation (*well established*) {5.4.1.4, 5.4.2.3 and 5.4.2.4}.

20 **The final underlying key intervention that emerges is strengthening environmental laws and policies and their implementation, and the rule of law more generally as a vital prerequisite to reducing biodiversity loss and human and ecosystem health (*well established*). This includes not only strengthening domestic laws but also international environmental laws and policies**, including mechanisms to both harness and rein in the power of business**.** Stronger international laws, constitutions, and domestic environmental law and policy frameworks, as well as improved implementation and enforcement of these rules, are critical in protecting biodiversity and nature's contributions to people (*well established)* {5.4.2.5}.

21 **Although these various changes may seem insurmountable when approached separately, each enabling intervention removes barriers associated with implementing others (*well established*) {5.4.3}. Accordingly and perhaps counter-intuitively, multiple interventions can be achieved more feasibly than individual ones (*well established*) {5.4.3.1}. Governments, businesses, and civil society organizations have many opportunities to boost ongoing processes and to initiate new ones that collectively constitute transformative change (*well established*) {5.4.3.2}.** The most important of these may involve laying the groundwork for changes to leverage points {5.4.1} and levers {5.4.2} at the root of environmental degradation or its reversal, by reducing opposition and obstacles, including those with interests vested in the status quo, but such opposition can be overcome for the broader public good {5.4.3.2}. Chapter 6 further details these challenges and also the opportunities and options for overcoming them, achieving long-term transformational change by initiating short-term measures today.

5.1 INTRODUCTION

While nature and its contributions to people are on a deeply unsustainable trajectory (c.f. chapters 2, 3, and 4), there is a multitude of voices demanding fundamental changes in the global socioeconomic structure and action. To change course toward a sustainable future, numerous organizations and individuals have called for actions at least since the 1980s (e.g., Our Common Future report, Agenda 21, The Future We Want). In response to the calls, many sustainability goals and targets have been set across local to global levels, including Aichi Biodiversity Targets and the 2030 United Nations Sustainable Development Goals (SDGs). Efforts around the world are under way for transformation to sustainability (CBD's Vision for Biodiversity 2050, Bennett *et al.*, 2016). Unlike the Intergovernmental Panel on Climate Change (IPCC), which has clear and single targets and timelines, single targets have limited capacity to address biodiversity declines. While proposals for using a combination of existing metrics exist (e.g., Red List index, Living Planet Index, Biodiversity Intactness Index) (Mace *et al.*, 2018), IPBES' work is guided by these and other existing targets including the Aichi Biodiversity Targets and the SDGs, which represent the closest option for an overall policy target for both ecosystems and human well-being.

In-depth understanding of the past trajectories and the current status of the global coupled human and natural system provides some useful knowledge needed to develop and employ models for a sustainable future (chapter 2; MA, 2005; Pimm *et al.*, 2014). Recent rapid and unprecedented changes, however, mean that historical trajectories may serve us very poorly. Therefore, forward-looking, scenario approaches are required that take those changes into account. Chapter 4 established that most trajectories rooted in current and past trends will fail to meet the full suite of Aichi Targets and biodiversity-relevant SDGs. However, chapter 4 also explored sustainability-oriented scenarios showing that positive futures are possible and failure is not inevitable. This indicates that it may not be too late to meet those goals and targets if bold systemic and incremental changes are made.

Change towards sustainability must be profound, systemic, strategic, and reflexive. Many signs of those changes are already starting to emerge, such as encapsulated in the notion of 'seeds of the good Anthropocene' (i.e., hopeful social-ecological practices ("seeds") that could catalyse and expand (grow) to produce more desirable futures, from addressing situations of social precariousness and vulnerability to recovering habitats for water protection and/or to conserve icons like the giant pandas (Bennett *et al.*, 2016; SFA, 2015; Yang *et al.*, 2017). The key implication of current scenario projections (chapter 4) is that successful change will not happen easily or spontaneously. It will likely require a broad and intense effort, informed by the best available understanding of local to global coupled human and natural systems dynamics. Most of the models and scenarios developed so far (chapter 4) have not been built, intended or applied in ways that address profound and systemic changes.

This finding from chapter 4 has bearing on chapter 5's position on sustainability transitions—as reformist, revolutionary, or reconfigurational (Geels *et al.*, 2015). A reformist position sees sustainability as the outcome of incremental changes and constant improvement of a current system. In contrast, revolutionary positions see sustainability as requiring a radical break with current trajectories. Finally, a reconfigurational position is something in between, involving context-related transformation of everyday practices and their structural embeddings. In this chapter we are philosophically ambivalent about these positions, but the chapter 4 finding suggests that a reformist position is likely to fail to achieve some relevant SDGs or Aichi Targets.

There is no single way to transform towards sustainability, and transformations will play out differently in different places (e.g., Arctic, Antarctic, temperate, tropical regions). The analysis in this chapter highlights possible pathways for transformative change to achieve widely agreed upon sustainability goals. It also identifies key leverage points (where a small change in one factor can generate bigger changes in other factors) (Abson *et al.*, 2017; Meadows, 1999) and 'levers' of change (promising management and governance interventions), without which successful transformation would not be possible. While we use the notion of 'levers' and 'leverage points' metaphorically, recognizing that global systems—as complex social-ecological systems—cannot be manipulated as neatly as can a boulder with a stick, it helps us to clarify our intentions.

What are those pathways, points of intervention and key levers or enabling interventions? In this chapter, we seek to answer this question, both for particular important objectives as well as their connections to other objectives within the larger system. We apply the 'nexus' concept to highlight connections representing stark synergies and trade-offs between different sectors and different goals, such as producing food or mitigating climate or producing energy while conserving biodiversity, resource use options, and ecosystem functioning (Liu *et al.*, 2018).

Two kinds of information are central for this chapter: existing scenarios and broader literatures pertinent to sustainability transformations. First, there are two relevant types of scenarios (target-seeking and policy-screening) that are constructed explicitly to achieve sustainability of Aichi

Targets and biodiversity-relevant SDGs. We interpret target-seeking scenarios as alternative pathways to meet one or multiple specific goals. As there are relatively few examples of such studies, we will also examine sustainability-oriented exploratory scenarios as a proxy. Assessing all these scenarios and pathways helps to explicitly analyse assumptions (e.g., economic, political, demographic, ecological, technological, ideological), pinpoint problems of spatial and temporal scales, and identify some complexities such as nonlinearities and regional differences (IPBES, 2016). Although the analysis is global, it builds on the IPBES regional assessments and meta-analyses of local studies in the literature. Particular emphasis is given to local participatory scenarios (e.g., participatory target-seeking scenarios for social transformation and empowerment) to illustrate and deepen the understanding of how global processes play out on a local scale. This is particularly important for biodiversity assessments, and with the emphasis on indigenous and local knowledge (ILK) and practices we anticipate innovative work on exploring alternative pathways at various scales. A second source of insight is necessary, however, because such scenarios represent only a narrow slice of the literature and a subset of the factors more easily rendered in models (e.g., only partly representing ILK), it is necessary to consult a broad range of literatures on societal and biodiversity change, including a burgeoning literature on pathways and transformative change.

In this chapter, we assess these various sources and distil from them alternative pathways for the transformations needed to achieve biodiversity objectives, the SDGs, to limit global temperature increase to 1.5 degrees Celsius above pre-industrial levels (i.e. The Paris Agreement of the UNFCCC) and to mitigate emerging and existing disaster risks (e.g., the Sendai Framework for Disaster Risk Reduction). We also draw upon policy- and management-screening scenarios, and their potential to simultaneously achieve multiple (sometimes conflicting) goals. This chapter culminates in key lessons for achieving multiple biodiversity and ecosystem service goals in the form of the 'leverage points' and 'levers' that offer unparalleled opportunities for changing unsustainable structures in today's economies and societies.

In the following sections, Section 5.2 provides a conceptual orientation for our approach and explains the methods for our analysis. Section 5.3 summarizes the results of the scenario assessment in the form of a cross-scale analysis of a nexus analysis with six cross-sector foci. Section 5.4 synthesizes insights from the scenario analysis and broader literatures, from which we have identified eight points of intervention ('leverage points') and five key enabling interventions ('levers') for sustainability. Finally, Section 5.5 provides general concluding remarks.

5.2 METHODS OF ASSESSMENT

5.2.1 Conceptual Framework for Assessing Transformation

5.2.1.1 Change towards sustainability requires addressing root causes, implying fundamental changes in society

The society/nature interface can be described in various ways (see for example Descola, 2013; Haraway, 1989; Jetzkowitz, 2019; Latour, 2004; Mol & Spaargaren, 2006; Takeuchi *et al.*, 2016; for further references to ILK-related concepts of the society-nature nexus see chapter 2 and IPBES, 2018). Here we follow IPBES' conceptual framework assuming that institutions, governance systems and other indirect drivers are "the root causes of the direct anthropogenic drivers that affect nature" (Díaz *et al.*, 2015; also see chapter 1). These root causes also affect all other elements of the society/nature interface, including interactions between nature and anthropogenic assets in the co-production of nature's contributions to people (Díaz *et al.*, 2015) In addition to the conceptual framework, we adopt systems thinking because it allows (1) the combination of biophysical and societal understanding of processes, which helps to identify seeds for change, and (2) the combination of results from quantitative and qualitative scenarios and other pertinent literature.

5.2.1.2 Conceptual frameworks addressing transformative change

Various approaches currently discussed in sustainability science address the question of how profound, systemic, and strategic-reflexive changes toward (more) sustainability can be initiated. Our selection of five approaches—complexity theory and the identification of layers of transformation and leverage points, resilience thinking, the multi-level perspective on transformative change, the systems of innovation approach and initiative-based learning—comprises those we identify as widely consistent with the IPBES conceptual framework and mandate. They provide useful concepts for the integration of knowledge on pathways towards a (more) sustainable future and facilitate our imagination throughout the whole chapter.

Complexity theory and leverage points of transformation

Complexity theory attempts to untangle emergent processes in coupled human and natural systems (Liu *et al.*, 2007; Nguyen & Bosch, 2013). It stresses the importance of specific contexts and interdependent influences among various components of systems, which may result in path dependency and multi-causality, where most patterns are products of several processes operating at multiple scales (Levin, 1992). One of the implications of such interdependence is that small actions can lead to big changes (Meadows, 1999), i.e., processes can be nonlinear (Levin, 1998; Levin *et al.*, 2013). These impactful actions are considered *leverage points* because they can produce outcomes that are disproportionate large relative to initial inputs (UNEP, 2012). Although identifying and implementing such leverage points is not easy, the results can be profound and lasting (Meadows, 1999).

Resilience, adaptability and transformability in social-ecological systems

In the context of pathways involving nature and people, changes are bounded not only by technological and social feasibility, but also by spatial and ecological characteristics. *Resilience* thinking enhances our systemic understanding by putting three aspects of social-ecological systems at the center: persistence, adaptability and transformability (Folke, 2016). Resilience refers to the capacity of a system—such as a village, country or ecosystem—to adapt to change, deal with surprise, and retain its basic function and structure (Berkes *et al.*, 1998; Nelson *et al.*, 2007). Adaptability—a component of resilience—represents the capacity to adjust responses to changing external drivers and internal processes, and thereby channel development along a preferred trajectory in what is called a stability domain (Walker *et al.*, 2004). Transformability is the capacity to cross thresholds, enter new development trajectories, abandon unsustainable actions and chart better pathways to established targets (Folke *et al.*, 2010).

A multi-level perspective for transformative change

Complementary to the perspectives above, the *multi-level perspective* sees pathways as an outcome of coupled processes on three levels—niches, regimes and landscapes (Geels, 2002). At the micro level, *niches* are the safe spaces where radical innovations are possible but localized. For innovations to spread to the meso level (*regimes*—interlinked actors and established practices, including skills and corporate cultures), they must overcome incumbent actors who benefit from the status quo. Regimes can either steer for incremental improvement along a trajectory or can affect change in the *landscape* (which includes factors like cultural values, institutional arrangements, social pressures, and broad economic trends). Change at this macro (landscape) level generally involves a cascade of changes, which also affect the regime itself. The multi-level perspective has been particularly useful in understanding socio-technical pathways, which tend to be nested and interdependent across levels. It raises strategic and reflexive questions—for instance, How can we identify actions that yield structural change from individual and local to societal levels, identifying and avoiding blockages and supporting transformations towards sustainability?

System innovations and their dynamics

The *system innovation* (or 'systems of innovation') approach provides a framework for policy interventions to address not only single market failures, but also interconnected challenges through a combination of market mechanisms and policy tools (e.g. OECD, 2015). This approach emphasizes that system innovation generally requires a fundamentally different knowledge base and technical capabilities that either disrupt existing competencies and technologies or complement them. As technology innovation proceeds, it also involves changes in consumer practices and markets, infrastructure, skills, policy and culture (Smits *et al.*, 2010). A key component of innovation for sustainability is thus supportive business models (Abdelkafi & Täuscher, 2016; Bocken *et al.*, 2014; Schaltegger *et al.*, 2012; Seroka-Stolka *et al.*, 2017). Governments also have a role in supporting transitions, however, which extends beyond orchestrating and coordinating policies and requires an active management of transformative change, especially sequencing of policies with the different stages of the transition (Huber, 2008; Mol *et al.*, 2009; Seroka-Stolka *et al.*, 2017).

Learning sustainability through 'real world experiments'

Several strands of research take an approach of so-called *real world experiments* (Gross & Krohn, 2005). These action research approaches emphasize how local and regional initiatives can foster shared values among diverse societal actors (Hajer, 2011), accelerating adoption of pathways to sustainability (Geels *et al.*, 2016). These experimental approaches contribute to niche innovations that are able to challenge existing unsustainable pathways and the regimes that maintain them. Bennett *et al.* (2016) suggest that emphasizing hopeful elements of existing practice offers the opportunity to: (1) understand the values (guiding principles) and features that constitute transformative change (referred to by the authors as the Good Anthropocene), (2) determine the processes that lead to the emergence and growth of initiatives that fundamentally change human-environmental relationships, and (3) generate creative, bottom-up scenarios that feature well-articulated pathways toward a more positive future (see also chapter 2.1). In the multi-scale scenario analysis applied in this chapter, local scenarios may be most closely connected to this approach.

Synthesis

The above conceptual approaches converge on the idea that profound changes in global socioeconomic systems towards sustainability occur as transformation of nested and interlinked structures and processes across various scales. In line with *systems of innovation* approaches, *resilience thinking* and the *multi-level perspective*, we consider profound changes as structural changes. However, these changes do not happen without activating impulses of individuals, groups and organisations. Accordingly, our methods for identifying pathways for sustainable futures includes two key elements: structural analyses of alternative pathways; and cross-cutting analyses of entry points for change ('leverage points') and enabling interventions for transformations ('levers').

5.2.2 Scenarios and Pathways

This chapter mobilises two complementary types of information: scenario and pathway analysis (section 5.3) and knowledge on transformative change (section 5.4). Scenario approaches help open up thinking about the future through qualitative, storytelling approaches and through quantitative systems modelling. These approaches allow for consistent analysis of complex systems and help identify consequences of changes (e.g., technological changes, changing behaviour, alternative management regimes for natural resources). At the same time, classical model-based scenario analyses often oversimplify social realities and have little detail regarding actors, behaviours and policy implementation. Socio-technical and social-ecological pathways analysis gives much more attention to different actors and actions and to finding entry points and levers towards changing pathways. Unfortunately, these approaches often lack a forward-looking perspective (they are generally retrospective) (Turnheim *et al.*, 2015). However, taken together with cross-cutting literatures on transformative change, they can bring a much needed multi-disciplinary perspective to identify and govern pathways for transformative change.

The terms **scenarios** and **pathways** are often used interchangeably especially by the global climate and integrated assessment modeling communities (Rosenbloom, 2017; Turnheim *et al.*, 2015). Here we distinguish the two concepts. **Scenarios** are plausible stories about how the future may unfold that can be told in words, numbers, illustrations, and/or maps—often combining quantitative and qualitative elements. Scenarios are not predictions about the future; rather they are possibilities used in situations of large uncertainty, based on specified, internally consistent sets of underlying assumptions (IPBES, 2016; Raskin, 2005). The global modelling community sometimes uses the term **pathway** to describe the *clear temporal evolution of specific scenario aspects or goal-oriented scenarios* (see **Boxes 5.1-3**). The concept of **pathways** in our chapter includes—but is not limited to—this meaning. More broadly, we consider pathways as "*alternative trajectories of intervention and change, supported by narratives, entwined with politics and power*" (Leach *et al.*, 2010). Scenario exercises may represent selected pathways and their underlying narratives.

5.2.2.1 Pathways for transformative change

The concept of pathways has become increasingly popular to analyse how specific sustainability objectives can be achieved. Pathway approaches attempt to manage complexity—in a bounded, exploratory way—and illuminate new ways of achieving specific societal goals (Geels & Schot, 2007; Turnheim *et al.*, 2015). A rich set of literatures on pathways towards sustainability examines how sustainability might be achieved through different trajectories, often addressing the politics of change and seeking profound changes in global socioeconomic structures (Edenhofer & Kowarsch, 2015; Geels & Schot, 2007; Grin *et al.*, 2010; Leach, 2008; Leach *et al.*, 2018; Loorbach *et al.*, 2017; Luederitz *et al.*, 2017; Olsson *et al.*, 2014; Raskin, 2008; Rosenbloom, 2017; Scoones *et al.*, 2015; Sharpe *et al.*, 2016; Swilling & Annecke, 2012). Few analyses straddle the breadth of perspectives considered here (Loorbach *et al.*, 2017; Turnheim *et al.*, 2015).

Pathways are mostly neither deterministic nor linear, but always context-dependent and evolutionary with emergent properties (the future being shaped by the past). Different pathways achieving the same goals will have different socioeconomic and environmental implications (e.g., effects on nature and its contributions to people). These include 'distributional impacts' that raise justice issues in a given system, and in connected systems through telecouplings (i.e., socioeconomic and environmental interactions over distances). Pathways may also be characterised in other ways: speed (time to reach the goals and targets), depth (degree of differences between starting points, current development trajectories and the goals and targets to be achieved), and scope (dimensions that change to achieve the goals and targets) (Turnheim *et al.*, 2015). As one insight that emerges, pathways of fundamental reconfiguration (or system transformation) often go through distinctive phases of destabilisation → disruption → breakdown of internal structures of the old system followed by an emergence and acceleration of novel features (Loorbach *et al.*, 2017).

In this chapter, pathways refer explicitly to trajectories toward the achievement of goals and targets for biodiversity conservation and management of nature and the full array of the SDGs. Because of the transformative change required, our analysis considers the departure from existing development pathways and vested interests/structures, to make space for new and more sustainable pathways

(Loorbach *et al.*, 2017; Sharpe *et al.*, 2016). Part of this departure may occur by deepening and accelerating existing processes of change.

There are several reasons to identify and analyse alternative pathways. First, no method can identify the best feasible pathway *a priori* due to the many uncertainties, complexities, and societal perspectives in coupled human and natural systems. There is a danger of bias in selecting pathways because the "definition of the alternatives is the supreme instrument of power" (Schattschneider, 1960, p. 66). Second, presenting alternative pathways and their uncertainties may allow for constructive public discourse. It is important to think about how pathways are framed as this shapes how they are understood and addressed, structuring the possibilities and privileging certain responses (Rosenbloom, 2017). Third, presenting alternative policy pathways and their trade-offs and consequences may help avoid the misuse of expertise in policy. With several pathways, policymakers cannot legitimize policy pathways by referring to an alleged "inherent necessity" of a certain policy pathway based on an apparent scientific consensus. To avoid severe bias in the assessment, pathways thus ought to reflect several politically important and disputed objectives, ethical values and alternative policy narratives.

5.2.2.2 Scenario studies

This chapter **combines multiple scenario studies** (through an analysis of their key premises, underlying narratives and results) **and other sources to inform our understanding about possible pathways to the SDGs**, as follows:

- **Types of scenarios considered:** Following the typology of the IPBES methodological assessment report on scenarios and models of biodiversity and ecosystem servicse (IPBES, 2016), our main focus in this chapter are **target-seeking scenarios**, also known as normative scenarios. Such scenarios are built by first defining a future target and then how to get from the present to this future, through quantitative and/or qualitative backcasting (Vergragt & Quist, 2011) or scenario-discovery techniques (Gao & Bryan, 2017), for instance. Since there are relatively few target-seeking scenarios, we also included **sustainability-oriented exploratory scenarios** and **policy-screening scenarios**. The sustainability-oriented exploratory scenarios were those scenarios of evolving key drivers, based on sustainability-oriented archetypes or storylines (Hunt *et al.*, 2012; IPBES, 2016; van Vuuren *et al.*, 2012). In policy-screening scenarios (also known as *ex-ante* scenarios), we analysed specific policy options implications in relation to a reference/*status quo* scenario.

- **Spatial scales:** To extract the key elements that constitute the pathways from scenarios, we employed a cross-scale analysis. While global scenarios indicate broad pathway alternatives, scenarios at finer spatial scales provide more detail and insights in the context of local or regional conditions. We therefore enriched our analysis by bringing elements from finer scales to the pathways discussion. Global scenarios alone may not capture the difficulties of implementing certain measures at local to regional scales, or the unwanted consequences of doing so.

- **Nexus-thinking approach:** Given the inherent complexity of analyzing possible achievement of multiple SDGs, we organized our literature search and analysis using a nexus approach to explore complementary and interconnected perspectives related to terrestrial, marine and freshwater social-ecological systems.

5.2.3 Nexus Thinking, Methods of Analysis

5.2.3.1 Nexus thinking to structure the analysis

Achieving goals and targets related to nature and nature's contributions to people requires holistic approaches to integrate multiple disciplines, across space, over time, and among organizational scales. The need for integration in solving complex problems has long been recognized, leading to a variety of approaches and areas of study. In this chapter, we use a systems approach and nexus thinking to identify synergies and trade-offs when discussing pathways for achieving the SDGs—incorporating thinking across scales, domains, sectors and disciplines (Liu *et al.*, 2015b).

The word nexus (derived from the latin "*nectare*", "to bind or tie"), has long been used in multiple fields to refer to approaches that address linkages between multiple distinct entities (Liu *et al.*, 2018). In recent decades, it became increasingly popular as applied to the study of connections among water, energy and food (the WEF or FEW nexus), usually in the context of climate change, and sometimes with the addition of other issues, such as biodiversity protection and human health (Albrecht *et al.*, 2018; Hoff, 2011). We find nexus thinking a valuable approach *to avoid the natural tendency to retreat into intellectual, sectoral, and institutional silos*. This holistic approach is imperative in the context of the SDGs, given that many of the targets are interconnected (Nilsson *et al.*, 2016) and such interactions can be synergistic and/or antagonistic, involving context-dependent trade-offs (Weitz *et al.*, 2018).

For the above reasons, we use nexus thinking to frame the problem of reaching multiple SDGs together. To keep our analysis manageable and understandable in the complex context wherein everything is connected, we structure our analysis around complementary perspectives, in a multilayered approach. Each perspective can be understood as a *focus* (or lens) to view in detail particular links between terrestrial, marine and freshwater social-ecological systems without disregarding linkages to other aspects **(Figure 5.2)**.

The following six foci reflect core challenges related to conserving nature and nature's contributions to people (the mandate of the global assessment) while achieving the SDGs, given both trade-offs and synergies:

1. *Feeding humanity while enhancing the conservation and sustainable use of nature;*
2. *Meeting climate goals without incurring massive land-use change and biodiversity loss;*
3. *Conserving and restoring nature on land while contributing positively to human well-being;*
4. *Maintaining freshwater for nature and humanity;*
5. *Balancing food provision from oceans and coasts with biodiversity protection; and*
6. *Resourcing growing cities while maintaining the ecosystems and biodiversity that underpin them.*

Our analysis respects the "interconnected and indivisible nature" of the 17 goals (UN, 2015). These six foci relate to all SDGs in some way, although they are oriented around some more strongly than others. Some SDGs are easily related to several of these foci (SDG 2 – Zero hunger, for instance), but human well-being, basic needs, human rights and nature protection underlie all the lenses, including attention to their implications for Indigenous Peoples and

THE NEXUS IN THE LANDSCAPE

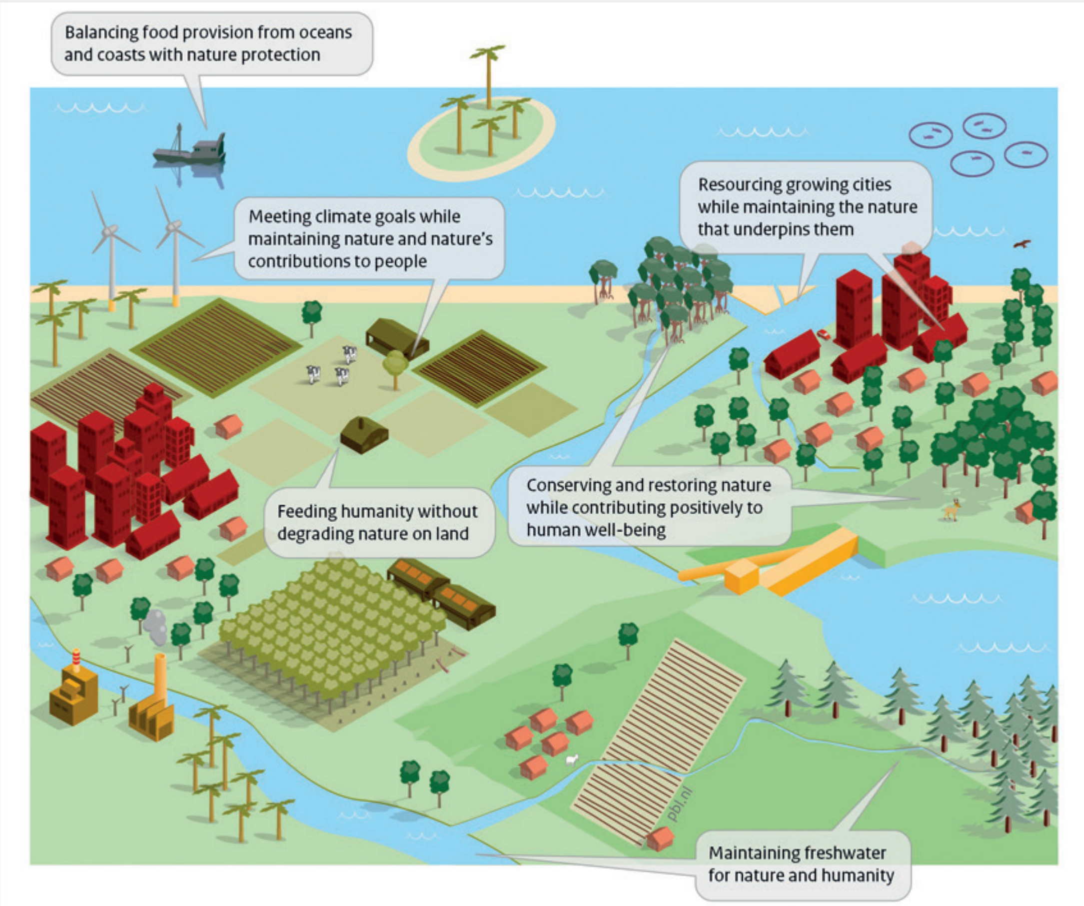

Figure 5 2 **The six interconnected foci of our nexus analysis.**

These complementary perspectives roughly followed divisions in the underlying scenario and pathways literatures addressing a variety of sustainability goals and targets (especially the UN's Sustainable Development Goals, SDGs, and the CBD's Aichi Targets). Source: PBL for this publication.

Local Communities (IPLCs), as **Figure 5.2** illustrates. The first three foci relate strongly to SDG 15 (Life on Land) and its interactions with other SDGs. The fourth addresses freshwater, connecting SDG 6 (Clean Water and Sanitation) to the first three foci through the WEF nexus. The fifth addresses marine resources, also linked to all other foci through the food system, water cycle, pollution and climate change concerns. Finally, the sixth focus addresses cities and their connection to the terrestrial, freshwater and marine resources previously discussed.

We structure our results in Section 5.3 (Pathways derived from the scenario review process) around these foci. For each subsection in 5.3.2, information is organized as follows:

- **Framing the problem**, a brief review about the current situation of the problem under analysis and major trends.
- **What do scenarios say about pathways to achieve the (relevant) SDGs?** We used the available information in the scenario literature (at multiple scales) to identify the *main measures* (actions, policies, governance premises, necessary changes) *directly or indirectly* (through quantified results or narrative premises, for instance) *underlying different scenarios in order to achieve the SDGs simultaneously*. Non-scenario literature was also used to reinforce or complement our synthesis approach.
- **Synthesis about the pathways**, we close each subsection with a synthesis of the main findings, including a diagram illustrating the pathways.

After the six subsections, we conclude 5.3 with a synthesis highlighting common threads across the six foci. We identify levers and leverage points of transformation with a focus on nature and nature's contributions to people (5.3.3). The section emphasizes core convergences and divergences across the different lenses, the synergies and trade-offs between the SDGs, and also the role nature and nature's benefits to people play in reaching the SDGs.

CROSS-SCALE ANALYSIS OF PATHWAYS TO THE SDGS USING NEXUS-THINKING

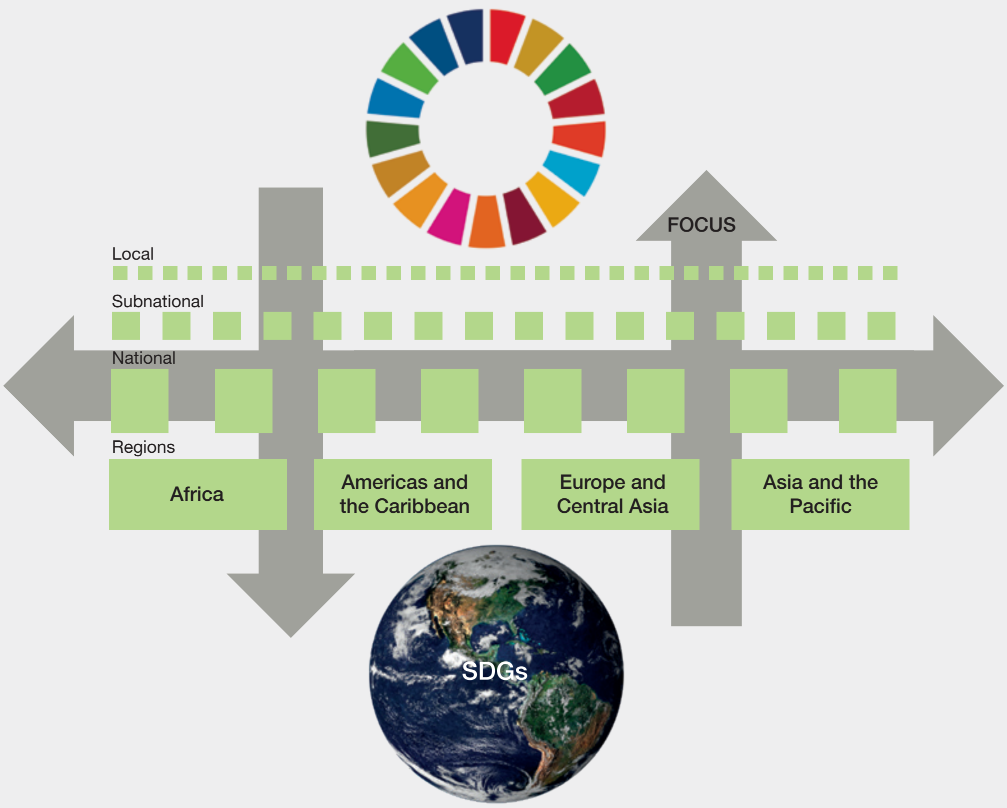

Figure 5 3 **Schematic representation of our multi-scale approach.**

The grey arrows denote the multiple foci we used to structure our analysis. For each focus, we strived to connect information across regions (horizontal arrow) and across spatial scales (vertical arrows).

5.2.3.2 Method for literature search at the global scale

Appendix 5.1 presents the basic search strings we used to select (target-seeking) global scale scenarios. Three alternative strings were used. The first one aimed to encompass all target-seeking scenarios related to nature and nature's contributions to people at the global scale, published after 2006. The second one restricts the search to the selected SDG clusters. The third one expands the selection to some key drivers of change, such as deforestation and restoration processes. To expand the set of studies underlying our analysis, we also investigated global scale exploratory and policy-screening scenario studies, which explicitly followed a sustainability focus in their storylines, with an intent to achieve the SDGs. An example is the new climate scenario SSP1 "sustainable world scenario" of the IPCC (van Vuuren *et al.*, 2017). We recorded key information for each scenario, as the basis for quantitative analysis presented in Section 5.3.1. The literature search for target-seeking scenarios at the global scale yielded 47 studies in total (see Section 5.3.1 and Table SM 5.2 B).

5.2.3.3 Cross-scale analysis

We defined a common process to incorporate information from other scales, to complement global scenarios. The initial source of information about scenarios and pathways at the sub-global scale (regional, national, subnational and local) were the fifth chapters of each of the IPBES regional assessments, which performed broad literature searches on scenarios pertaining their regions. A complementary literature search was conducted for each specific lens/perspective under analysis, similar to the one performed at the global scale. Based on the combined results from all these sources, we tabulated key information about each scenario at different scales (Appendix 5.2). We organized five tables with core information about terrestrial scenario studies (global and the four IPBES regions), and one related to marine scenarios. Each table describes the following: Scale, Region/system, Goal/vision, Type of scenario, Sectors covered, Pathway elements (measures, policies, changes), Scenario 'short name' and Complete reference. We then performed an iterative process to synthesize key information for each scale and region, related to each focus of analysis. Based on this systematization, we distilled key components of pathways projected to achieve the SDGs, which formed the basis for the subsections "What do scenarios say about pathways to achieve the SDGs?", complemented by non-scenario literature and cross-regions linkages. Although we did not adopt a typology of pathways (as in the IPBES European and Central Asia regional assessment), in 5.3 we do indicate alternative—and sometimes contrasting—pathways emerging from the literature. **Figure 5.3** depicts this process.

As mentioned before, this chapter combined methods and procedures to interpret sustainability transitions from different scientific angles. As such, it is an effort towards inter- and transdisciplinary triangulation. Combining the findings from different approaches may enable a more encompassing and more legitimate understanding of the processes, outcomes, and impacts of possible pathways to sustainability. We hope that this will in turn yield more appropriate and legitimate implications for practice and policy (as discussed in 5.4 and chapter 6).

5.3 PATHWAYS DERIVED FROM THE SCENARIOS REVIEW PROCESS

5.3.1 Results of the assessment of global scenarios

5.3.1.1 Overview

The literature search on target-seeking and policy-screening scenarios yielded 47 scenario studies with global coverage. Qualitative, storytelling ("narrative") scenarios were assessed for additional information to determine if, when and why SDGs could be achieved **(Figure 5.4 B)**. At the global scale, target-seeking scenario research is much less elaborated than exploratory scenario research (chapter 4). The IPBES methodological assessment on scenarios and models of biodiversity and ecosystem services notes that target-seeking and policy-screening scenarios have been applied to decision-making mostly at regional and local scales (IPBES, 2016), and therefore are not common at the global scale. Backcasting and scenario-discovery approaches were rare at the global scale, likely due to the inherent complexity of the task at that scale.

The scenarios evaluated consisted of target-seeking scenarios (e.g., Leclère *et al.*, 2018; PBL, 2012; van Vuuren *et al.*, 2015; see **Boxes 5.1 and 5.2**, respectively), followed by policy-screening scenario studies (e.g., Visconti *et al.*, 2016), 'sustainability' exploratory scenarios (e.g., Raskin

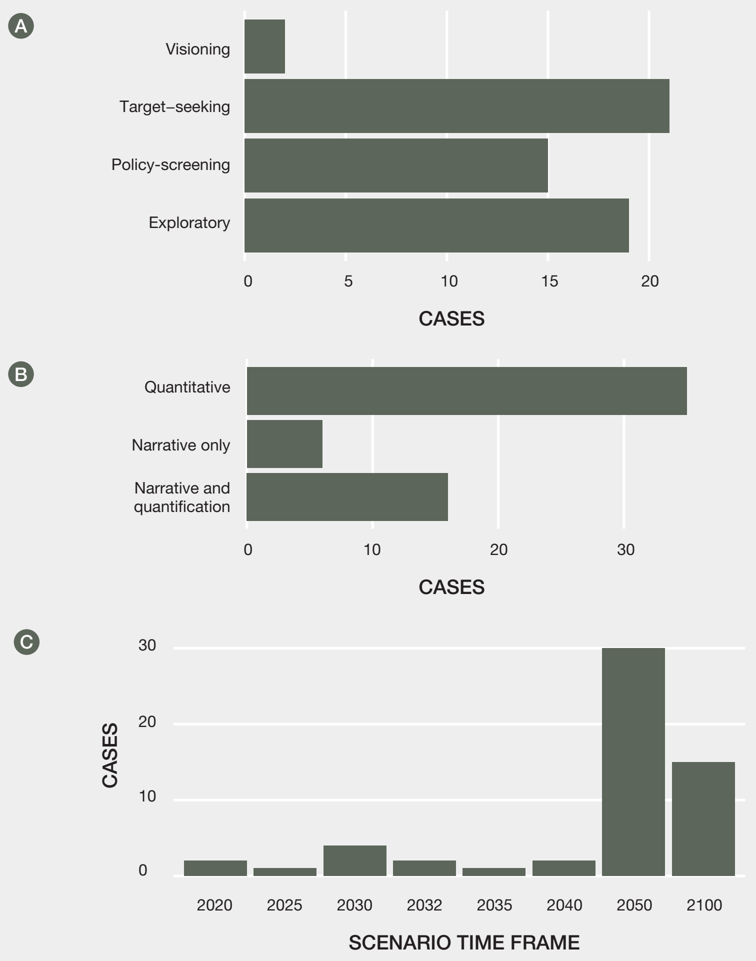

Figure 5 4 **The number of studies from the review on target-seeking scenarios that fulfill the following:**

A target-seeking scenarios, policy-screening scenarios, 'sustainability' scenarios of exploratory exercises, and visioning exercises; B using a quantitative approach, a narrative approach, or both together; and C applying different time frames of analysis (N=34; a given study could score in multiple categories for panel A).

et al., 2002) and a small number of visioning studies (e.g., WBCSD, 2010; see **Figure 5.4 A**). Visioning studies were only taken into account if they went beyond qualitative description of future trajectories for a certain sector and provided quantification and analysis of pathways to realize that vision. The analysis revealed that most selected studies include both narratives (storylines) and quantification of scenarios using models (e.g., UNEP, 2002 Sustainability First Scenario).

In most global scenario studies, biodiversity, ecosystem services (or nature's contributions to people), and implications for human well-being are a few of many aspects being analysed (e.g., PBL, 2012). Regarding temporal scale, long-term projections are most common across the selected studies (present to year 2050, **Figure 5.4 C**). This finding is in line with IPBES (2016), which states that international environmental assessments including scenario exercises typically focus on long timescales. Decision-making, however, often requires both short-term and long-term perspectives (IPBES, 2016), so considering scenarios across different temporal scales is important.

The majority of studies relied on expert knowledge. Only a few incorporated indigenous and local knowledge and perspectives or stakeholder consultations (e.g., Springer & Duchin, 2014). This finding corresponds to IPBES scenarios assessment conclusion that participatory scenario studies predominantly have a local-scale focus, while global scale scenario studies are often developed using expert-based approaches (IPBES, 2016). Participatory scenario methods enhance the relevance and acceptance of scenarios for biodiversity and ecosystem services (IPBES, 2016), and their application could be taken up more often in global-scale scenario exercises.

Sectors most commonly considered

The agricultural sector was the sector most commonly addressed in the scenarios, with 32 of the 47 studies investigating the relationships between agriculture and

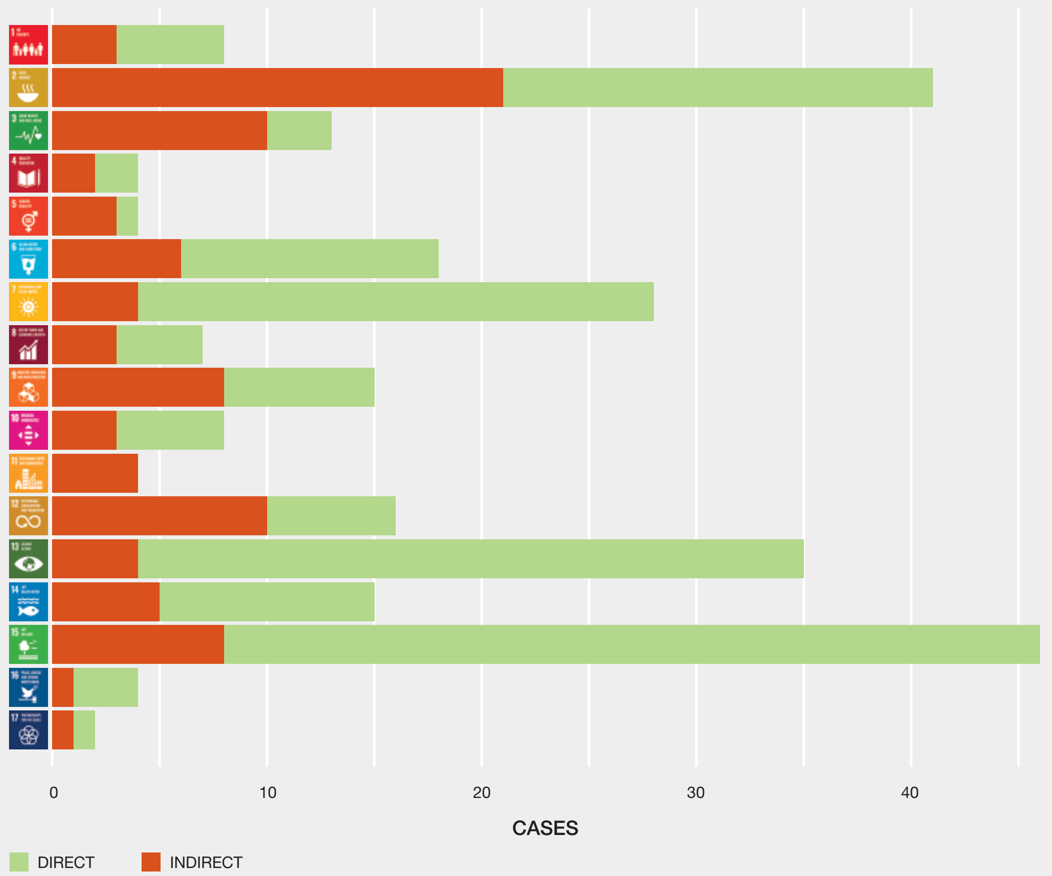

Figure 5 5 **Sustainable Development Goals in Scenarios. Green ("direct") represents scenarios that address an SDG directly; orange represents scenarios that address an SDG only implicitly ("indirect").**

other sectors and factors such as biodiversity, biofuels, deforestation, and climate change (e.g., Eitelberg *et al.*, 2016; Erb *et al.*, 2013; PBL, 2012; Smith *et al.*, 2013; van Vuuren *et al.*, 2015). Concerns ranged from feeding the growing human population to addressing threats from biofuels and managing the availability of land and water (e.g., Flachsbarth *et al.*, 2015; Odegard & van der Voet, 2014; Wirsenius *et al.*, 2010).

The second most prevalent sector was forestry, with 17 studies addressing issues such as land degradation, and competition with agricultural production (e.g., Kraxner *et al.*, 2013; Stavi & Lal, 2015; van Vuuren *et al.*, 2015). In particular, these scenarios addressed issues such as reducing carbon emissions from forest degradation, and competition between forests and biofuel crops (e.g., Smeets *et al.*, 2007; Zarin *et al.*, 2016). Energy and water sectors were considered by 17 and 7 studies respectively. In terms of water, issues addressed include river fragmentation as a threat to river biodiversity, availability of water for agricultural production (particularly emphasizing the threat of agricultural expansion for water resources), and general water efficiency measures needed to reach targets (e.g., Grill *et al.*, 2015; Springer & Duchin, 2014; WBCSD, 2010). The energy sector was addressed largely through efforts to reduce carbon emissions via clean technology, and the competition for land associated with these efforts (Prieler *et al.*, 2013; Rogelj *et al.*, 2018a; van Vuuren *et al.*, 2010, 2017).

SDGs most commonly considered

SDGs pertaining to terrestrial systems were most frequently considered. In particular, SDGs 2 and 15 were commonly investigated, analyzing trade-offs between food security and (terrestrial) biodiversity **(Figure 5.5)**. These studies provide input to investigate the foci on "*Feeding humanity while enhancing the conservation and sustainable use of nature*" Section 5.3.2.1) and "*Conserving and restoring nature on land while contributing positively to human well-being" (*5.3.2.3)*.* Also studied quite frequently were SDGs 6, 7, 12, 13 and 14. The results from the review as well as additional literature thus enables investigating foci related to *Maintaining freshwater for nature and humanity (5.3.2.4)* and *Balancing food provision from oceans and coasts with nature protection (SDG 14, 2, 12; 5.3.2.5)*. Although many studies addressed SDGs 13 and 15, including in concert, additional literature was consulted for the specific lens considering the means of "*Meeting climate goals while maintaining nature and nature's contributions to people***"** (5.3.2.2). Few target-seeking scenarios addressed SDGs 4, 5, 11, 16, and 17. Because of the undisputed relevance of an urbanizing society, however, we investigated the focus "*Resourcing growing cities while maintaining the nature that underpins them*" (5.3.2.6) based largely on secondary literature.

5.3.1.2 Core global studies: integrated pathways to achieve multiple goals

Because detailed examination of particular scenarios and trade-offs is instructive in ways that a general synopsis is not, this section reviews core global studies discussing integrated pathways for achieving multiple goals. Here we pinpoint key characteristics of the pathways discussed in these studies, which feeds into the multi-scale analysis in 5.3.2.

Roads from Rio+20 pathways: this study culminates a series of linked papers and reports (Kok *et al.*, 2018; PBL, 2012, 2014; van Vuuren *et al.*, 2015). It used a backcasting approach to explore the level of effort needed to achieve selected SDGs (accounting for feasibility constraints). **Three alternative pathways were quantified and compared to the 'trend' scenario; each achieved the goals despite variation in management and behaviour change**. The goals align closely with the SDGs (they were based on internationally agreed goals and targets prior to the SDGs) and involve provision of energy and food while mitigating climate change (2 degrees), providing clean air and halting biodiversity loss. The study also examined some related issues including nitrogen, water, and health in the context of population, economic growth, energy and land use. The scenarios were quantified using an integrated assessment model framework IMAGE in combination with related models for biodiversity, human health and climate policy (GLOBIO, GISMO and FAIR, respectively) to provide a global overview while differentiating between world regions (see the IPBES regional assessments for region-specific results). **Box 5.1** synthesizes how the three pathways differ and some key quantitative results in relation to biodiversity.

Alternative pathways to the 1.5 degrees target based on the Shared socioeconomic pathways (SSPs). The SSPs represent five different development trajectories: i.e., sustainable development (SSP1), global fragmentation (SSP3), strong inequality (SSP4), rapid economic growth based on a fossil-fuel intensive energy system (SSP5) and middle of the road developments (SSP2; all are used extensively by the Intergovernmental Panel on Climate Change (IPCC)). Each of the SSPs portrays a storyline quantified using models. These storylines can be combined with different assumptions about climate policy to form a larger context of socioeconomic development and level of climate change (mitigation scenarios, c.f. Riahi *et al.*, 2017; Rogelj *et al.*, 2018b). The sustainable development scenario (SSP1) combined with stringent climate policy is a scenario exploring the route towards a more sustainable world, although the SDGs were not targeted in its development. Mitigation scenarios that achieve the ambitious targets included in the Paris Agreement typically rely on greenhouse gas emission reductions combined with net carbon dioxide removal from the atmosphere, mostly accomplished through

Box 5 1 Roads to Rio+20 Pathways.

Several key **premises** underlie the alternative pathways (Figure Box 5.1.a) and their achievement of sustainability goals (Kok *et al.*, 2018; Table SM 5.3.3):

The **Global Technology pathway** assumes that sustainability objectives are pursued mainly by large-scale application of technological solutions. A high level of international coordination through—for example—trade liberalization and the expansion of global markets drives these responses in all world regions. In terms of land use, sustainable intensification in agriculture may lead to a "land sparing" effect, i.e., efficient use of some lands for production would allow sparing other land from conversion to agriculture and/or dedicate them to conservation (Balmford *et al.*, 2005). The protected area system focuses on continuous natural areas away from existing agricultural land to minimise conflict with agricultural expansion, but large natural areas are not necessarily connected.

The **Decentralized Solution pathway** consists of solutions and technologies that can be implemented on a smaller scale resulting in multi-functional mosaic landscapes and regional diversity, in line with regional priorities. Local and regional markets drive demand. Ecological innovation in mixed land-use systems where natural elements and production landscapes are interwoven may result in a "land sharing" effect (Balmford *et al.*, 2005). Agricultural intensification is achieved by using ecological techniques, such as intercropping, agroforestry, and natural pest control, in combination with natural corridors interwoven with agriculture to enable the extensive use of ecosystem services (Pretty, 2008; Tittonell, 2014). In this pathway, agricultural landscapes comprise at least 30% of natural elements acting as corridors between natural areas, hence reducing fragmentation and providing ecosystem services.

The **Consumption Change pathway** starts from implementing a set of behavioural changes in favour of less resource-intensive consumption. These include ambitious efforts to reduce waste, increase recycling in production chains, reduced energy- and material- intensive lifestyles and a shift towards moderate consumption of meat and dairy, in line with health recommendations. Alongside land "sparing" and "sharing" pathways above, this is the "caring" pathway, reflecting the importance of personal behavioural and consumption choices. This pathway assumes a reduction of 50% in food waste and losses, equalling 15% of the production (IMECHE, 2013). Increases in agricultural productivity are only slightly higher than in the 'trend' scenario. Food consumption change is derived from the Willett diet, characterized by a low meat and egg intake (Stehfest *et al.*, 2009; Willett, 2001).

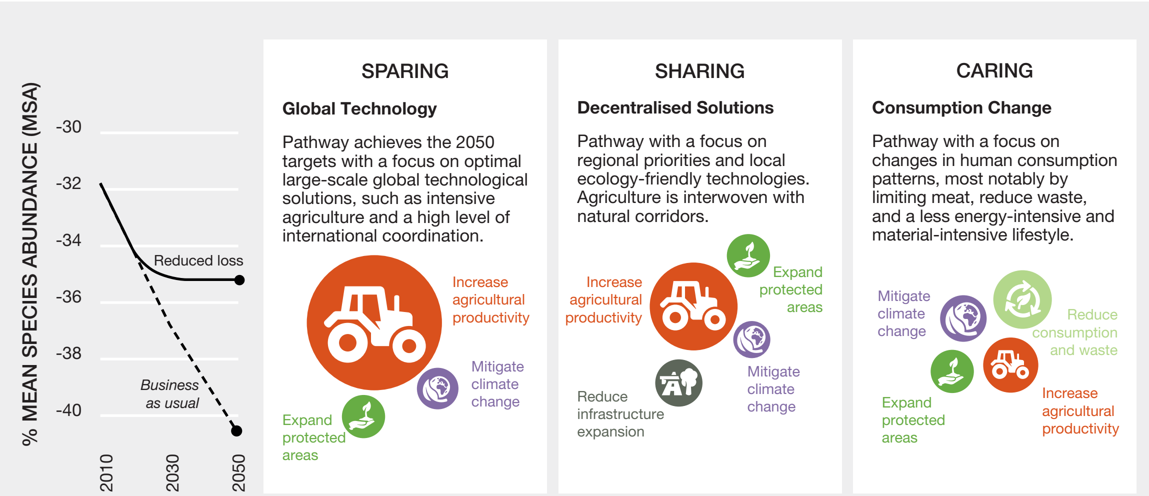

Figure 5 1 A Schematic representation of three alternative pathways to reduce biodiversity loss represented in the Roads to Rio+20 study (see Table SM 5.3.1/5.3.2 for comparison of premises).

Source: PBL (2017).

Results

According to the study, all pathways achieve the assumed 2050 targets (Table SM 5.3.1) and would reduce biodiversity loss in the coming decades (avoided Mean Species Abundance (MSA) loss is 4.4-4.8% MSA, compared to 9.5% MSA loss in the 'trend' scenario **(Figure Box 5.1.b)**. Under the Global Technology pathway the most important contribution by far comes from increasing agricultural productivity on highly productive lands. Under the Consumption Change pathway, significant reduction in consumption of meat and eggs as well as reduced waste means that less agricultural production would be required, thus reducing associated biodiversity loss. Under the Decentralised Solutions pathway, a major contribution comes from avoided fragmentation, more ecological farming and reduced infrastructure expansion. Under all scenarios, climate change mitigation, the expansion of protected areas and the recovery of abandoned lands also significantly contribute to reducing biodiversity loss. Further positive results could be achieved by combining various options from the pathways, especially by increased consumption changes in the other pathways. This would result in reversing trends of biodiversity loss (see **Box 5.3** on Bending the curve).

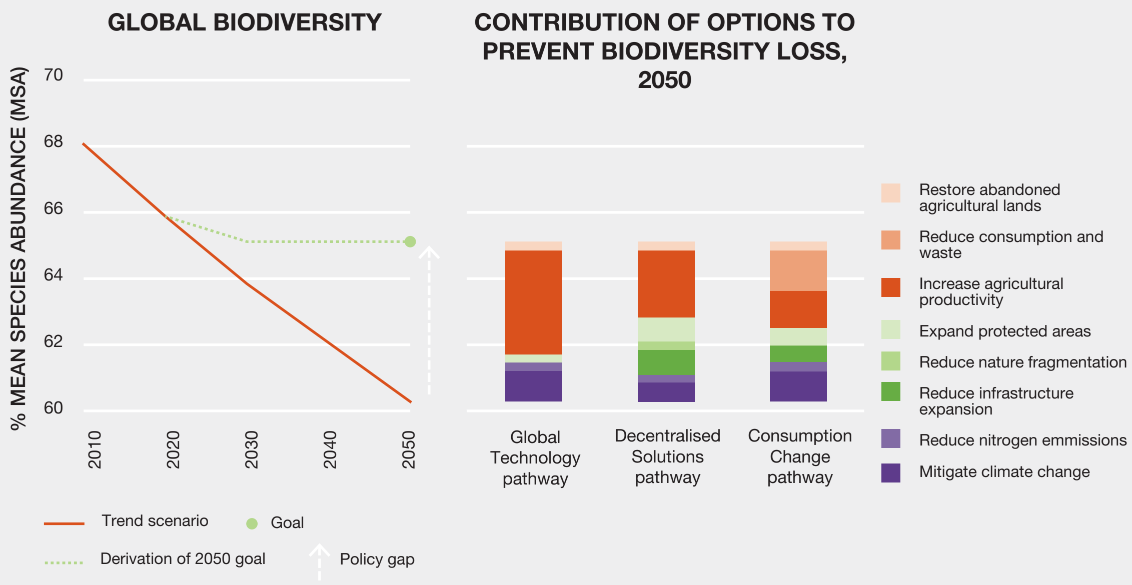

Figure 5 1 B **Measures in the alternative pathways that contribute to biodiversity goals.**

The Rio+20 scenarios have also been used to explore the impact of alternative pathways on extinction risk and abundance of large mammals, revealing that both bottom-up behavioural change (Consumption Change) and top-down technology and policy changes (Global Technology) can reverse global biodiversity decline in the short term, but the onset of delayed climate change impact may require further mitigation strategies.

This study was also one of first to discuss synergies and trade-offs among food, biodiversity, energy, health and climate targets (see Table SM 5.3.3), some of which were explicit in the models. However, some potential trade-offs remain unquantified, such as the use of pesticides and their impacts on health and biodiversity. Source: PBL (2012).

The following publications contain more details (Kok *et al.*, 2018; PBL, 2012, 2014; van Vuuren *et al.*, 2015; Visconti *et al.*, 2016), and there is discussion about their regional results in each IPBES regional assessment.

large-scale application of bioenergy with carbon capture and storage, and afforestation (Doelman *et al.*, 2018; Rogelj *et al.*, 2018a). Using the IMAGE integrated assessment model, van Vuuren *et al.* (2018) explored the impact of **additional measures (beyond SSP mitigation scenarios)** that also include lifestyle change, additional reduction of non-CO_2 greenhouse gases and more rapid electrification of energy demand based on renewable energy (see **Box 5.2** for more detail).

Alternative pathways for bending the biodiversity curve: the 'Bending the Curve' study (Leclère *et al.*, 2018) quantitatively modelled ambitious target-seeking scenarios aiming at reversing biodiversity trends in the 21st century from negative to positive (Mace *et al.*, 2018). This interdisciplinary effort between different modelling communities focuses on biodiversity as affected by human land use and relies on: a) spatially explicit datasets of biodiversity, modelled impacts of land use on biodiversity, and existing scenario frameworks (e.g., SSPs and representative concentration pathways, RCPs); b) integrated assessment models, in particular their spatially explicit land-use modeling components; c) global spatially explicit biodiversity models (also used in chapters 2 and 4) assessing an array of biodiversity impacts from land-use changes. The storylines of existing SSP/RCP scenarios were enriched with more ambitious conservation storylines and quantified via additional datasets generating new scenarios of future trends in land use. These new scenarios considered further actions for biodiversity, such as increased conservation efforts (increased extent and management efficiency of protected areas, increased restoration and landscape-level conservation planning), but

Box 5 2 Alternative pathways to the 1.5 degrees target.

Compared to the default SSP2 1.9 and 2.6 (radiative forcing level of 1.9 and 2.6 W m–2 in 2100, respectively), alternative scenarios to achieve the 1.5 degrees goal are built using the following premises (van Vuuren *et al.*, 2018):

- Rapid application of best available technologies for energy and material efficiency in all relevant sectors in all regions;
- Higher electrification rates in all end-use sectors, in combination with optimistic assumptions about integration of variable renewables and costs of transmission, distribution and storage;
- High agricultural yields and application of intensified animal husbandry globally;
- Implementation of best available technologies for reducing non-CO_2 emissions and full adoption of cultured meat in 2050;
- Consumers change their habits towards a lifestyle that leads to lower GHG emissions (less meat-intensive diet, less CO_2-intensive transport, less intensive use of heating and cooling and reduced use of several domestic appliances);
- Lower population growth (compatible with SSP1);
- The combination of all options described above.

Results

Although the alternative options explored greatly reduce the need to actively remove atmospheric CO_2 to achieve the 1.5 °C goal, nearly all scenarios still rely on bioenergy with carbon capture and storage and/or reforestation (even the hypothetical combination of all alternative options still captured 400 $GtCO_2$ via reforestation). Although not directly estimating impacts on biodiversity targets, these results are important due to the large-scale reforestation process envisioned in the mitigation scenarios. The set of alternative scenarios suggests a diversity of possible transition pathways, including via changing consumption patterns.

The results point out the need for a more diverse portfolio of options than currently discussed in the mitigation scenarios and an open debate concerning their contributions. This could provide more flexibility to ensure that goals are reached. However, it is important to note that the adoption of alternative pathways also might convey substantial regional impacts. To illustrate, **Figure Box 5.2** compares the spatially explicit results of SSP1 and SSP1 1.9, as implemented by the IMAGE model in Doelman *et al.* (2018).

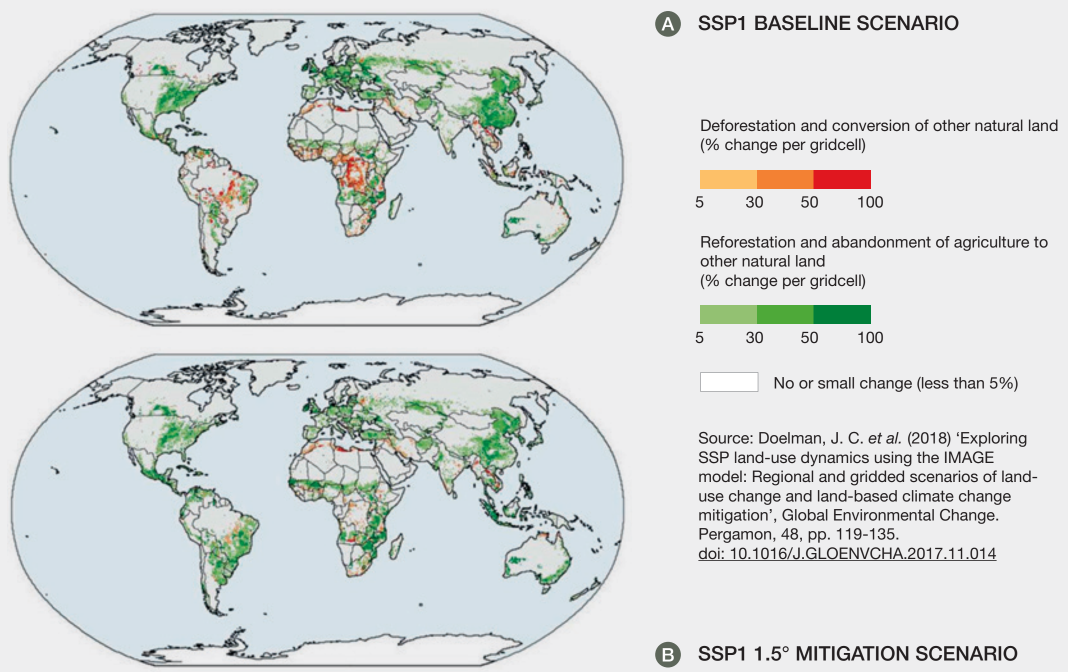

Figure 5 2 **Change in land use (percentages of grid cells) between 2010 and 2100; deforestation and conversion of other natural land to agriculture (red) and reforestation and abandonment of agriculture to other natural land (green) for SSP1 baseline scenario and SSP1 1.5 °C mitigation scenarios (1.9 W/m²).**

Source: PBL for this publication.

Box 5 3 Bending the curve scenarios: towards pathways for ambitious biodiversity targets.

In addition to a baseline (BASE) scenario (based on the "Middle of the Road" SSP2), this study considers six "wedges scenarios" in which various efforts are implemented in order to "bend" the curve of biodiversity loss. The scenarios do not assume strong climate mitigation efforts, nor do they account for future changes in climate or any threat to biodiversity other than habitat loss. The **premises** underlying the six wedge scenarios are as follows:

Increased conservation efforts ("C scenarios"):

a) Increasing protection: any change in land use detrimental to biodiversity (according to PREDICTS' Biodiversity Intactness Index (Hudson *et al.,* 2017)) is ceased from 2020 onwards for all areas identified by the potential protected areas layer (see sections 4.1 and 5.2 in Leclère *et al.*, 2018).

b) Increasing restoration and landscape-level conservation planning: over the entire land area, incentives are gradually put in place to favor land-use changes resulting in biodiversity improvements from 2020 onwards. The net impact on biodiversity (gain or loss) of a particular land-use change is based on PREDICTS' Biodiversity Intactness Index for the two land uses, while the relative importance (for biodiversity) of a given parcel of land derives from the regional restoration priority layer (see sections 4.3 and 5.2 in Leclère *et al.*, 2018).

Demand-side efforts beyond SSP1 ("DS scenarios"):

a) Shifting towards healthier diets: dietary preferences evolve towards 50% less meat compared to the baseline scenario, linearly between 2020 and 2050 (the corresponding animal calories are replaced by plant-based calories) except for regions with low shares of meat in diets like Middle-East, Sub-Saharan Africa, India, Southeast Asia and other Pacific islands (where dietary preferences follow the reference scenarios)..

b) Reducing waste throughout the food supply chain: total waste (losses in harvest, processing, distribution and final household consumption) decreases by 50% by 2050 compared to the baseline, linearly between 2020 and 2050.

Supply-side efforts ("SS scenarios"):

a) Sustainably increasing productivity: crop yields develop following SSP1, assuming in particular a rapid convergence of land productivity in developing countries to that of developed countries.

b) Increasing trade in the agricultural sector: trade of agricultural goods develops according to SSP1, with a more globalized economy and reduced trade barriers.

Combined efforts scenarios: the above efforts are combined by pairing increased conservation and supply-side efforts in the C+DS scenario, increased conservation and supply-side efforts in the C+SS scenario, and all efforts together in the integrated action portfolio (IAP) scenario.

Results show that bending the curve is possible within the 21st century for several feasible driver scenarios. **Figure Box 5.3** shows that combining different action wedges allow biodiversity trends to be reversed before 2050 (IAP scenario), instead of continuing declines for BASE scenario. This predicted reversal of trends is similar across all metrics, indicating that future land-use scenarios can be robustly favorable to biodiversity.

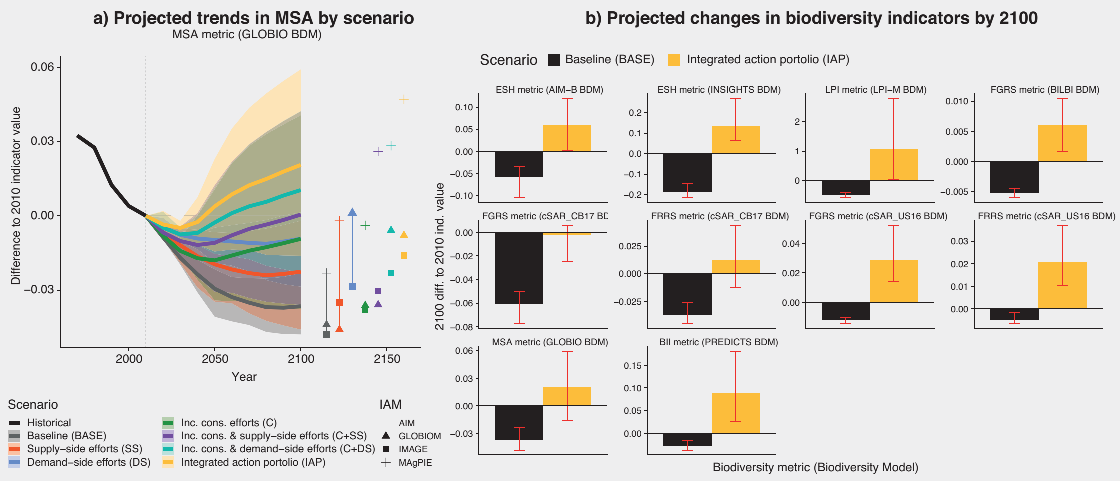

Figure 5 3 **Illustration of results from the Bending the Curve fast-track analysis results.**

The left panel illustrates the estimated change in GLOBIO's Mean Species Abundance index (MSA) from 2010 to 2100 (as compared to 2010) for the land-use component of four integrated assessment models (AIM, GLOBIOM, IMAGE and MAgPIE; the range across IAMs is depicted by ribbons, the average by lines) and 7 scenarios between a business as usual

(BASE) and an Integrated Action Portfolio (IAP) scenario cumulating all efforts to reverse biodiversity trends. The right panel presents the change in various biodiversity indicators estimated by 2100 as compared to 2010 for 2 scenarios (BASE and IAP): BILBI and countryside Species Area Relationship models provide measures of extinctions (the Fraction of Regionally/Globally Remaining Species FRRS & FGRS); GLOBIO and PREDICTS both provide measures of ecosystem integrity through the Mean Species Abundance (MSA) index and the Biodiversity Intactness Index, (BII) respectively; INSIGHTS and AIM-Biodiversity provide a measure of habitat changes through the Extent of Suitable Habitat (ESH) index; and wildlife population density trends are estimated through the Living Planet Index (LPI). The bars indicate the average across IAMs, while red error bars indicate the dispersion across IAMs.

The multi-model assessment framework allows for quantitative assessment of uncertainties associated with land-use projections and their underlying drivers. The contribution of individual drivers and combinations of drivers to stepwise biodiversity improvements has also been quantified. For example, although larger conservation and restoration efforts are key to halting loss and engaging biodiversity onto a recovery path, such a reversing of global biodiversity trends will only be possible by 2050 if our food system achieves a feasible but ambitious transformation.

also demand-side (shift in diets towards less meat, reduced waste) and supply-side efforts (crop yield improvement and reduced trade barriers). Scenarios were fed into the integrated assessment models to generate land-use change projections. Finally, biodiversity models were used to assess whether these spatially explicit land-use change projections over the 21st Century are able to reverse biodiversity trends on a multitude of biodiversity indicators. **Box 5.3** describes measures embedded in the pathways and synthesizes core results.

Two core conclusions can be drawn from the analysis of these studies:

1. **Pathways and narratives:** Different pathways can potentially yield achievement of the same sustainability goals, sometimes with contrasting narratives.**Recognizing the existence of alternative narratives, including their complementarities and tensions, is central to advance the discussion of necessary transformations**, as alternative pathways pose different challenges, trade-offs and synergies among targets (Leach *et al.*, 2010; Luederitz *et al.*, 2017; **Boxes 5.1-3**). For instance, focusing on lifestyle change may greatly decrease the need for future choices related to resource use. Different narratives also uncover power structures and winners and losers of anticipated transformations. Reduced meat production may have implications for economies of producing countries. System lock-ins may be reinforced by certain pathways. Relying only on land-sparing pathways may have positive implications for large-scale industrial agriculture while undermining small-scale farmers. In the following sections, alternative narratives and pathwaysare recognized and highlighted through examples.

2. **SDGs and the Paris Agreement goals:** Scenarios consistent with the Paris goals to reduce GHG emissions include options such as switching to zero- and low-carbon energy options, increasing energy efficiency, using carbon capture and storage (CCS), reducing non-CO_2 GHG emissions, eliminating emissions related to land-use change and stimulating afforestation. Van Vuuren *et al.* (2018), for instance, concluded that GHG targets can be achieved through reduced production of meat and dairy products and intensification of agricultural production, together limiting conversion of unmanaged land. Such a pathway may also promote land-use changes that minimize releases of carbon stored in vegetation and soils, thereby potentially preserving some biodiversity-rich areas. However, mitigation scenarios may also rely on development of short-rotation bioenergy plantations—increasing pressure to convert unmanaged land—and afforestation of non-forested areas for both carbon sequestration and extractive use.

These climate mitigation scenarios suggest four key points: (a) the **biodiversity impacts of afforestation** will depend on where afforestation occurs and how the resulting plantations and forests are managed; (b) such pathways indicate a **land-constrained scenario for food production** due to competition with large-scale reforestation and biofuels; (c) a key underlying premise of the SSPs pertains to population size and ensuing consumption trends. The population dynamics for the different SSPs (Abel *et al.*, 2016) range from a very high global population of almost 13 billion by 2100 down to just 7 billion in SSP1—a shade lower than the current population of 7.6 billion. Therefore, **the feasibility of the options discussed above depends on reduced population growth, and consequently a considerably lighter pressure on resources** (energy, land, water)(see 5.4.1.2). Finally, (d) **such studies assume appropriate, timely and effective governance of such large-scale transformations** in different geographic contexts (see 5.4.2.1-5).

5.3.2 How to achieve multiple SDGs: a cross-scale analysis using nexus thinking

5.3.2.1 Feeding humanity while enhancing the conservation and sustainable use of nature

Framing the problem

Today, agriculture accounts for 38% of Earth's terrestrial surface (Foley *et al.*, 2011) and produces enough calories for all people in the world (Ramankutty *et al.*, 2018). Many millions of people have been lifted out of hunger but food security continues to be a major challenge globally (Godfray *et al.*, 2010). The Food and Agriculture Organization (FAO) reports that the number of undernourished people increased to 821 million in 2017. Similarly, stunting and wasting continue to affect children under the age of five, with more than 150 million and 50 million children affected in the same year, respectively. At the same time, obesity is rising, affecting more than 670 million people worldwide (FAO, 2017).

There are many reasons for the mismatch between the increased availability of food and the continued existence of undernourishment. On the supply side, food production is not evenly distributed globally, and regions differ in terms of yield, irrigation, nutrient application and climate impacts, among other factors (Lobell *et al.*, 2011; Monfreda *et al.*, 2008; Mueller *et al.*, 2012; Ramankutty *et al.*, 2018; Searchinger *et al.*, 2013). Consumption is further impeded in some places by access, affordability, and poverty. Added to this is increasing food waste across the food value chain from production to consumption (Gustavsson *et al.*, 2011; Odegard & van der Voet, 2014; Smith *et al.*, 2013), market influences on food price (Headey & Fan, 2008; O'Hara & Stagl, 2001) and other factors affecting the distribution of food. Besides, in many regions the expansion of industrial agriculture–via incentives from trade agreements, government subsidies, and global mergers of large agribusinesses corporations–threatens small-scale agriculture, still a significant and in many countries the main contributor to food production and food security (IPES-Food, 2016). Beyond agriculture, hunting, gathering, and herding systems continue to be crucial for locally appropriate food security, and such systems have sometimes suffered at the expense of subsidies for and externally imposed notions of appropriate nutrition and food production (Council of Canadian Academies, 2014; EALLU, 2017). Despite their importance, these non-agriculture food systems represent an important gap in literatures on scenarios and pathways (except for fishing, see 5.3.2.5 and also 5.3.2.4); accordingly, our focus in this section is largely on agriculture.

Agriculture is a fundamental driver of global biodiversity loss through its area expansion and the increase of pollutants and of resources used in production (including irrigation water, fertilizers and pesticides) (see chapters 2, 3). Meanwhile, agriculture depends strongly on healthy ecosystems for a diversity of supporting ecosystem processes, including nutrient remineralization, soil health, insect pollination, and biological pest control (Power, 2010; Seppelt *et al.*, 2017). **The core question addressed here is whether and how agriculture and associated food systems will be able to meet the needs of the global population in the coming decades, without further degrading natural resources (and possibly even restoring some).** Addressing this question requires consideration of the globalization of food systems and the varying contributions and roles that different regions play in food production **(Figure 5.6)**.

We organize the discussion about pathways in relation to agricultural production, the supply chain and consumers. While much of the literature has focused on reconciling agricultural production and conservation, other issues also need attention. These include food distribution systems, waste, poverty, inequality and personal food preferences, all of which provide direction for tackling hunger and malnutrition, and ultimately, environmental degradation (Bennett, 2017; Cassidy *et al.*, 2013; Tilman & Clark, 2014). It is also critical to reflect on current trends of global food production systems becoming more capital-intensive. The concentration of food production in fewer hands, and the centralized control of inputs pose a significant threat to small-scale agriculture (FAO, 2017).

What do scenarios say about how to achieve these goals?

Agricultural production pathways

Considerable debate addresses how best to balance food production and nature conservation, minimizing land clearing and biodiversity loss (Balmford *et al.*, 2005; Bruinsma, 2011; Erb *et al.*, 2016; Foley *et al.*, 2011; Kok *et al.*, 2014; Phalan *et al.*, 2011; Smith, 2018; Smith *et al.*, 2013; Tscharntke *et al.*, 2012). Two interconnected aspects are key: (1) where food is produced and nature is conserved (spatial distribution of nature and agricultural lands), and (2) how and by whom food is produced.

Some argue that achieving this balance requires land sparing (intensification of agriculture for high yields and the setting aside areas for conservation—a binary approach), while others argue for land sharing (integrated approaches where these two forms of land-use are blended and wildlife-friendly techniques are applied). Based on different approaches, scholars independently come to the conclusion that agricultural yields can be increased substantially without further expansion of agricultural area (Delzeit *et al.*, 2018; Erb *et al.*, 2016; Mauser *et al.*, 2015) but with intensification of land use. In the extreme, biologist E. O. Wilson has called for protecting “half Earth” (Wilson, 2016), producing more and healthier food through sustainable intensification on existing farmland, and returning the other half of land to nature. Lately, many authors have argued that this simplified dichotomy (“land sparing” vs. “land sharing”) limits future possibilities (Kremen, 2015). A stringent application of one of the two strategies everywhere is undesirable, as what is optimal may strongly differ regionally based on socioeconomic, cultural and ecological characteristics—and the region’s role in global food systems **(Figure 5.6)**.

This leads to another important debate regarding the nature and scale of agricultural systems. Agro-industrial systems, consisting of input-intensive monocultures and industrial-scale feedlots currently dominate farming landscapes (FAO, 2017; IPES-Food, 2016). The uniformity at the heart of these systems, and their reliance on chemical fertilizers, pesticides and preventive use of antibiotics, systematically yields negative outcomes and vulnerabilities, which might lead to system lock-ins (Geiger *et al.*, 2010; Hunke *et al.*, 2015; Wagner *et al.*, 2016). To avoid such problems, there is a need to scale up sustainable practices, including agroecology (FAO, 2017; IPES-Food, 2016; Muller *et al.*, 2017; Rockström *et al.*, 2017). A recent study explored the role that organic agriculture could play in sustainable food systems (Muller *et al.*, 2017). These authors showed that—in combination with reductions of food waste and food-competing feed, with correspondingly reduced production and consumption of animal products—organic agriculture could feed the world using less land than the reference scenario, and that it could also bring several environmental benefits, including a decrease in pesticide use.

Agroecology practices can play a key role. Applied to small-holders they can boost food security; smallholders rather than large-scale farming are the backbone of global food security efforts, given that 80% of the hungry live in developing countries and 50% are smallholders (Tscharntke *et al.*, 2012). The move towards sustainable agriculture may include the adaptation and transfer of agroecological practices and technologies to areas and nations with relatively low yields (‘bridging the yield gap’; Pradhan *et al.*, 2015). Such efforts could enable more efficient nutrient use worldwide, but they are no substitutes for regional strategies to achieve food security. Payment for ecosystem services (PES) programs are frequently mentioned in regional to local scenarios (SM 5.2) as an important complementary measure to help facilitate the transition (e.g., Kisaka & Obi, 2015; see 5.4.2.1 about incentives).

The majority of current integrated global scenarios largely rely on a land sparing/intensification approach (see Section 5.3.1.2, SM 5.2.B), allocating food production across the globe to the most suitable lands, and envisioning extensive land restoration. The Roads to Rio+20 is an exception, also representing a land sparing pathway **(Box 5.1)**. Regional to local scenarios (SM 5.2.C to F) tend to explore multiple pathways, detailing the challenges and opportunities of such pathways, and in some cases contrasting perspectives. Regional to local scenarios highlight the following as core pathway elements to achieve the goals of food production and nature conservation: spatial planning; strengthened protected areas; measures to avoid the social and environment rebounds of agricultural intensification; resolution of land tenure issues; routine law enforcement; participation in strengthened governance structures. The importance of international cooperation and cross-national governance structures has been stressed by several scenario studies given the globalization of production and the need to upscale local innovations (Geels *et al.*, 2016; PBL, 2014; Pouzols *et al.*, 2014; van Vuuren *et al.*, 2015).

Consumer pathways: changes and diets and pressure for certified products

Consumers can influence supply chains and agriculture production through consumption choices, including changes towards healthier and environmentally friendly diets. The heterogeneous trends of population growth and urbanization across different regions, and different countries’ positions as consumers or producers in the globalized food system, underlie such discussions.

At the global scale (Table SM 5.2 B), several authors have discussed the impacts of alternative diets on land-cover change and, consequently, on biodiversity loss (Delzeit *et al.*, 2018; Erb *et al.*, 2016; Popp *et al.*, 2010; Schader *et al.*, 2015; Stehfest *et al.*, 2009). For instance, Stehfest *et al.*’s (2009) four scenarios of dietary variants—all of which reduce meat consumption (ranging from partial to complete elimination of meat from global diets)—lessened projected land-use change (and impacts on ecosystem services more broadly) and emissions. Potential instruments discussed in such studies include regulation, economic incentives, and information campaigns.

Regional to local scenarios focused less on consumption and diet changes, except in the US and EU. In the **United States**, for instance, Peters *et al.* (2016) evaluated ten alternative diet scenarios (varying the content of meat and dairy consumption) based on projected human carrying capacity (persons fed by unit land area). Their results indicate that: (a) diet composition greatly influences overall land footprint, and imply very different allocation of land by crop type; (b) shifts toward plant-based diets may need to be accompanied by changes in agronomic and horticultural research, extension, farm operator knowledge, infrastructure, livestock management, farm and food policy, and international trade; and (c) diets with low to modest amounts of meat outperform a vegan diet, and vegetarian diets including dairy products performed best overall.

In meat producing countries like **Brazil**, recent scenario studies tend to focus on measures to transform cattle ranching (see for example MCTI, 2017; Strassburg *et al.*, 2014; see Table SM 5.2.C). These studies argued that even with current trends in meat consumption, a boost in the current low productivity of the sector—combined with adequate measures to avoid social and environmental rebounds of intensification—could decrease deforestation and even liberate area for restoration. In contrast, global scenarios, particularly recent ones aligned to 1.5°C targets (see **Box 5.2 and 5.3**), tend to consider a reduction in meat consumption as a necessary measure, given competition for land (biofuels and reforestation), emission and pollution concerns.

Finally, consumer pressure for goods produced in an environmentally friendly and socially just manner is a strong mechanism for transforming food systems. Certification programs are often mentioned as an important pathway element in scenarios at all scales (SM 5.2), as further discussed below (and in 5.4.3.2; chapter 6).

Supply chain pathways

Supply chains link producers and consumers via local to global networks of processors, traders, retailers, investors and banks. The relatively small number of actors (compared to producers and consumers) provides opportunities for levers of transformation, as such key actors may influence decisions made by primary producers and others throughout supply chains (Kok *et al.*, 2014). Partnerships between public and private actors involved in supply chains seem promising for mainstreaming biodiversity protection and engaging multiple levers of change.

A good example of supply chain initiatives is the Soy Moratorium in Brazil's Amazon, a production system telecoupled via global markets (see also chapter 6). This Moratorium was the first voluntary zero-deforestation agreement implemented in the tropics and set the stage for supply-chain governance of other commodities, such as beef and palm oil (Gibbs *et al.*, 2015). In response to pressure from retailers and nongovernmental organizations (NGOs), major soybean traders signed the moratorium, agreeing not to purchase soy grown on lands deforested after July 2006 in the Brazilian Amazon. A monitoring system verifies individual producers. Although few integrated quantitative scenarios represented such measures explicitly, qualitative scenarios often mentioned them as key elements, tied to other governmental and civil society measures (for instance, Aguiar *et al.*, 2016).

The trend of concentration of food systems in few companies also tends to create major asymmetries in economic and power relations. Such asymmetries must also be addressed to ensure fairness and underpin necessary changes regarding food waste, distribution, and more sustainable and healthier practices (IPES-Food, 2016). One core example is the vested interests of large companies that produce pesticides and chemical inputs.

5.3.2.2 Meeting climate goals while maintaining nature and nature's contributions to people

Framing the Problem

Under a business-as-usual scenario, global demand for land is projected to increase substantially. An expansion of agricultural land and bioenergy plantations may leave little room for preserving natural habitats and biodiversity (Secretariat of the Convention on Biological Diversity, 2014). Many more stringent climate mitigation scenarios (reaching 450 ppm but also 550 ppm CO_2eq concentrations by 2100) rely on large-scale deployment of bioenergy with carbon capture and storage (BECCS) (Rogelj *et al.*, 2018b; Smith *et al.*, 2014). The bioenergy crop area required by 2100 is estimated at 150 to 600 Mha (Rogelj *et al.*, 2018a). Potential implications for biodiversity have been explored (Meller *et al.*, 2015), but only a few global bioenergy scenario studies explicitly addressed biodiversity targets and SDGs (e.g., Beringer *et al.*, 2011; Erb *et al.*, 2012; Heck *et al.*, 2018; Leclère *et al.*, 2018; see also 5.3.1.2). It has also been suggested that freshwater biodiversity is severely threatened by ongoing and future development of hydropower (Hermoso, 2017), but we are not aware of any global hydropower scenarios that explicitly address impacts on biodiversity and ecosystem services.

Global energy production from various bioenergy systems in 2018 generates about 50 EJ per year. In some regions, bioenergy production generates substantial economic benefits for states and increases employment and individual incomes (Smith *et al.*, 2014). Bioenergy production in scenarios reaching the 1.5° C target range from 40 to 310 EJ per year (Rogelj *et al.*, 2018b). Major bioenergy systems include industrial organic residues, forest and agricultural residues, dedicated biomass plantations and optimal forest harvesting. Dedicated biomass plantations include annuals (e.g., corn and oil crops), perennials (e.g., sugarcane, oil palm and perennial grasses) and wood-based systems such as short rotation woody crops (see Creutzig *et al.*, 2015; Smith *et al.*, 2014 for a more detailed classification.

Substantial climate mitigation potentials could also be generated by reducing demand for traditional biomass, which until recently accounted for ~80% of current bioenergy use and helps meet the cooking needs of

~2.6 billion people (Chum *et al.*, 2011; IEA, 2012). Ecosystem-based non-bioenergy climate mitigation also has substantial potential without adverse effects on biodiversity and food security. So-called 'natural climate solutions' include a wide range of measures, such as reforestation and changes in forest management, fire management, changes in fertilizer use in grasslands as well as coastal and peat restoration (Griscom *et al.*, 2017). But all such solutions have adverse effects, so scenarios are key for considering trade-offs in context.

Land-based climate mitigation scenarios achieving multiple sustainability goals

Global bioenergy potentials and scenarios are commonly generated with Integrated Assessment Models (IAMs), which explicitly account for competing land demands (Rogelj *et al.*, 2018b), and are consistent with estimates from other global biophysical modelling approaches (Beringer *et al.*, 2011; Erb *et al.*, 2012; Heck *et al.*, 2018; Kok *et al.*, 2018; Meller *et al.*, 2015). BECCS from dedicated plantations in accordance with SSP2 and RCP2.6 would most likely lead to a further transgression of planetary boundaries for land-system change, biosphere integrity and biodiversity, and biogeochemical flows (Heck *et al.*, 2018). So-called second- and third-generation bioenergy systems (IEA & FAO, 2017), such as the use of agricultural residues, and biofuels produced from lignocellulosic ethanol and algae, often have a lower impact on biodiversity and the environment in general. An interpretation of the SSPs with five IAMs with distinctive land use models suggests substantial potential for climate mitigation through improved agricultural management and second-generation bioenergy crops in combination with BECCS, while preserving or even enhancing the extent of natural ecosystems and carbon stocks, in particular in an SSP1 world (Popp *et al.*, 2017).

However, in current models for large-scale scenarios, biodiversity targets have only been included in rather simplistic ways, such as an additional constraint for land allocation, e.g., excluding protected areas from bioenergy or food production (Beringer *et al.*, 2011; Erb *et al.*, 2012; Meller *et al.*, 2015). The global pathways (SSPs) and associated models still lack many processes important to quantify changes in habitat quality and biodiversity (Harfoot *et al.*, 2014; Meller *et al.*, 2015), particularly at local scales (Kok *et al.*, 2017), implying high uncertainty in future impacts of large-scale deployment of bioenergy systems on biodiversity and ecosystem services (Meller *et al.*, 2015).

Griscom *et al.* (2017) estimated that 'natural climate solutions' can provide 37% of the climate mitigation needed until 2030 for a better-than 66% chance of reaching the 2 degrees Celsius target, without adverse effects on biodiversity and food security, and with likely co-benefits for biodiversity. Carbon storage, climate mitigation effectiveness and biodiversity can, for example, be promoted if trees are allowed to grow older in certain temperate forests (e.g., Law *et al.*, 2018). Results from a global analysis, however, suggest that optimal forest harvest ages in terms of climate mitigation efficiency (including life-cycle analyses) often deviate from those ages that promote biodiversity the most (Oliver *et al.*, 2014) and high biodiversity is often found in low-biomass systems (Bond, 2016; Myers *et al.*, 2000). Abreu *et al.* (2017), for example, found strong negative effects of fire suppression on plant and ant richness in the savannahs of the Brazilian Cerrado, a global biodiversity hotspot, where carbon storage was increased by fire suppression. Nevertheless, a recent study with a global integrated energy-economy-land-use modelling system including a wide range of climate mitigation activities suggested that it is feasible to reach the 2 degree Celsius and even the 1.5 degree Celsius target of the Paris Agreement, with co-benefits for air quality, food and energy prices, and without substantial negative effects on biodiversity (Bertram *et al.*, 2018). These outcomes were achieved via a reduction of agricultural trade barriers, no further increases in first-generation biofuels, an increase in the protected forest area and an increase in carbon pricing (Bertram *et al.*, 2018). 'Bending the curve' scenarios also suggest substantial potential for improved land management and synergies between climate mitigation and biodiversity, but also trade-offs (see section 5.3.1.2, **Box 5.3** and Kok *et al.*, 2018).

Synthesis and open questions about climate mitigation pathways

Different bioenergy systems can have very different impacts on biodiversity and ecosystem services (Meller *et al.*, 2015). Intensively managed bioenergy monocultures, such as sugarcane, maize/corn, soybeans, and oil palm have roughly similar negative impacts as other forms of intensive agriculture on biodiversity and ecosystem services more broadly, which raises concerns about their future deployment. The global potential of second- or third-generation bioenergy systems is more uncertain than the above first-generation systems. Alternatively, establishing bioenergy systems that integrate multiple functions can also promote biodiversity (Creutzig *et al.*, 2015; Meller *et al.*, 2015). For example, when combined with agroforestry or installed on degraded land, oil palm plantations can generate co-benefits on food production, carbon storage and biodiversity (Creutzig *et al.*, 2015; Smith *et al.*, 2014). It has also been suggested that marginal and degraded lands, currently not used for food production, might have a substantial potential for bioenergy production. However, how much land is available or unused has been debated (Creutzig *et al.*, 2015), and many areas considered marginal in terms of their agricultural or forestry potential harbour rich biodiversity (Bond, 2016; Myers *et al.*, 2000). Also, 'low-input high-diversity' (LIHD) mixtures of native grassland perennials, for example, can have higher energy yields than monocultures, increase carbon storage in soils, benefit biodiversity and ecosystem services, and they can be grown on agriculturally degraded soils (e.g., Tilman *et al.*, 2006b). Even for the European Natura2000 protected area network, a large potential of low-input high-diversity bioenergy production has been suggested (Van Meerbeek *et al.*, 2016). However, intensively managed monocultures often have higher yields and are, therefore, favored by current price and policy incentives, even though they perform poorly when considering multiple ecosystem services (e.g., Werling *et al.*, 2014). Forest residue use also has large potential, but it can also decrease old-growth forest structures, such as deadwood, which are important habitats for many species (Meller *et al.*, 2015).

Large-scale deployment of intensively managed first-generation monoculture bioenergy crops would have profound negative impacts on biodiversity and many ecosystem services but a comprehensive quantification of such effects at the global scale is missing. A recent study concluded that a low-emission scenario with BECCS might affect global vertebrate diversity as negatively as a high-emission scenario with stronger climate change but without BECCS (Hof *et al.*, 2018). Nevertheless, substantial additional potential for bioenergy exists without compromising biodiversity and ecosystem services, but the implications of different bioenergy systems for a variety of ecosystem services and sustainable development are often poorly captured in scenario studies.

Other ecosystem-based climate mitigation activities surely also have large potential for sequestering carbon cheaply while providing multiple ecosystem services, and boosting biodiversity (Griscom *et al.*, 2017). It is, however, difficult to generalize under which conditions certain management actions preserve biodiversity and achieve an optimal supply of several ecosystem services. Optimal approaches (balancing trade-offs of production and conservation) are region- and ecosystem-specific and include considerations of both biological and livelihood diversity. For instance, among the guiding principles proposed to maximize carbon storage and commercial forestry in landscape restoration schemes in the tropics is that afforestation should not replace native grasslands and savannahs (Brancalion & Chazdon, 2017).

The reviewed literature suggests that governance and shifted economic incentives will be necessary to promote the development of those land-based climate mitigation activities that secure multiple ecosystem services (Grubler *et al.*, 2018; IEA & FAO, 2017; van Vuuren *et al.*, 2015; Werling *et al.*, 2014). Demand-side climate mitigation measures, e.g., reduced waste or demand for energy and livestock products, are often more likely to achieve multiple goals, such as greenhouse gas emission reduction, food security and biodiversity protection than bioenergy plantations (Grubler *et al.*, 2018; Smith *et al.*, 2013). Low energy demand pathways, with reduced or no reliance on BECCS, would likely result in significantly reduced pressure on food security (Roy *et al.*, 2018). Some demand-side changes will require life-style changes, which can take more time than supply-side measures and pose challenges to influence by policies (Smith *et al.*, 2013; see also section 5.3.2.1 and 5.4.1.2 on consumption). However, current observable trends suggest a substantial potential to decrease the global energy demand despite rises in population, income and activity. A global scenario study based on these trends suggest that the 1.5 degrees Celsius target and many SDGs could be met without relying on negative emission scenarios (Grubler *et al.*, 2018), but most global studies concluded that some negative emissions might still be necessary even with optimistic assumptions concerning, e.g., lifestyle changes, reforestation and energy transitions (e.g., van Vuuren *et al.*, 2018). Further transdisciplinary research and improved models for ecosystem management and bioenergy scenarios are, however, necessary to close the knowledge gaps outlined above.

5.3.2.3 Conserving and restoring nature on land while contributing positively to human well-being

Framing the problem

The concept and practice of protected areas (PAs) has been at the heart of conservation policy since its inception in the 19th Century. Traditionally, PAs were implemented by governments using strict conservation approaches, which treated biodiversity protection as incompatible with social-cultural practices and benefits. By the 1980s, classic conservation models evolved towards more participatory management and inclusive conservation approaches. The Convention of Biological Diversity (CBD) called for the protection of at least 17% of terrestrial and inland water by 2020, especially areas of particular importance for biodiversity and ecosystem services (a target nearly met, although with limited spatial and ecological representativeness; chapter 3).

Existing PAs suffer from several challenges. Isolated areas can lack functional connectivity for species. Some authors argue that biodiversity within PAs continues to decline, questioning the effectiveness of current conservation management approaches (Coad *et al.*, 2015), while other studies document the effectiveness of PAs, at least relative to other land uses (Gray *et al.*, 2016). Today's PAs are likely not adequate to conserve many species whose distributions will shift due to climate change (Secretariat of the Convention on Biological Diversity, 2014); they may also suffer from additional degradation (e.g., increased fire risk). In this context, to protect habitats and species and maintain connectivity, attention has been directed towards biodiversity-rich land under **private** ownership and under the governance and management of IPLCs, who already contribute to the management of around 40% of PAs globally (Drescher & Brenner, 2018; Garnett *et al.*, 2018; Kamal *et al.*, 2015; Maron *et al.*, 2018; Paloniemi & Tikka, 2008; Tikka & Kauppi, 2003).

In addition to conservation, **restoration** of ecosystems and landscapes (although in its early stages) is rapidly becoming a new major driver of changes in nature and NCP (Aronson & Alexander, 2013). Aichi Biodiversity Target 15 together with the "Bonn Challenge"—a global restoration initiative—have established a goal of restoring 150 million hectares of deforested and degraded land globally by 2020. The New York Declaration on Forests expanded this goal to 350 million hectares restored by 2030 (Chazdon *et al.*, 2017). In addition, several large-scale restoration initiatives have recently emerged around the world (Latawiec *et al.*, 2015).

What do scenarios say about how to achieve these goals?

Sustainability-oriented global scenarios usually consider the maintenance or expansion of protected areas (PA) networks as central. For instance, the Rio+20 target-seeking scenarios implemented three different assumptions regarding the extent and distribution of PAs. The Global Technology pathway, reflecting a land-sparing approach, explores the expansion of agricultural areas close to existing agricultural areas, and assumes that 17% of each of 7 biodiversity realms will be protected in PAs situated far from agriculture. In the Decentralized Solutions pathway, production areas are shared with nature elements covering at least 30% of landscapes to reinforce PAs, which cover 17% of all 779 ecoregions. As previously discussed, Kok *et al.* (2014) show that both strategies may reduce biodiversity loss, but the biodiversity preserved, and the spatial distribution of losses differ greatly (see **Box 5.1**).

Any approach entails international cooperation including funding from different sources (e.g., Global Environment Facility, Butchart *et al.*, 2015) to facilitate and scale up protected areas. This is especially true in developing regions facing challenges to effective protection in current and future protected areas. Scenarios at local and national scales emphasize, as a critical element of pathways, the improvement of monitoring systems and the enforcement (and protection) of environmental legal frameworks (Aguiar *et al.*, 2016).

Also, at local to regional scales (Appendix 5.2), scenarios show that **existing protected areas are at risk**, mostly due to political changes, incomplete implementation and institutional weaknesses (see chapter 3 for a discussion). In Latin America, for instance, the network of PAs and indigenous lands is one of the most important factors managing the Amazon deforestation frontier (Aguiar *et al.*, 2007; Pfaff *et al.*, 2015; Soares-Filho *et al.*, 2010). However, these areas suffer the impacts of illegal logging and fires, and are threatened—above all—by political and economic pressure to give way to agricultural expansion, major infrastructure and natural resource extraction projects (Aguiar *et al.*, 2016; Ferreira *et al.*, 2014).

The **expansion of protected areas networks** faces competition with other land uses. In a global analysis, Venter *et al.* (2018) found that both old and new protected areas did not target places with high concentrations of threatened vertebrate species, but instead appeared to be established to lessen conflict with agriculturally suitable lands. In Africa, for instance, although the need for expanding protected area networks is great, some authors argue that improved governance of existing PAs may provide more biodiversity benefits (Costelloe *et al.*, 2016).

Local scenarios propose a combination of protected areas and land-sharing approaches through landscape planning. The 'land sharing' strategy has the potential to improve connectivity between natural areas by boosting natural elements within the agro-ecological matrix. Meanwhile, increasing productivity reduces the land area needed for agricultural production and consequently reduces biodiversity loss. But the sustainability of that intensification depends on reserving large areas within the agro-ecological matrix for natural elements (Perfecto & Vandermeer, 2010).

The **spatial arrangement** of protected areas and natural elements also matters, as explored by landscape planning to meet human needs via multiple ecosystem services while maintaining biodiversity in functioning ecosystems. This can be done on private lands, optimizing trade-offs between environmental, social and economic benefits (Kennedy *et al.*, 2016; Seppelt *et al.*, 2013). Such planning can also consider the importance of mosaics of diverse governance types and the overlap of PAs with Indigenous lands and community-governed conservation areas that can enhance opportunities to meet human needs and ecosystem function. In the Andes, for instance, the spatial and temporal organization of farms and agricultural practices at multiple scales—including some agroforestry practices—could improve yield and boost ecosystem services (Fonte *et al.*, 2012).

Restoration

Ecosystem restoration can also deliver multiple benefits to people and help achieve multiple Sustainable Development Goals (Possingham *et al.*, 2015). Successful cases of restoration are found all over the world (see Fisher *et al.*, 2018). Achieving these targets would ease pressing global challenges such as climate change mitigation (Chazdon *et al.*, 2016) and adaptation (Scarano, 2017), and biodiversity decline (Crouzeilles *et al.*, 2017). Large-scale restoration may play a critical role in enhancing nature's contributions, but it represents yet another competing use of already scarce land resources with potential impacts on local livelihoods (Adams *et al.*, 2016; Hecht *et al.*, 2014).

Box 5 4 Restoration experiences in Brazil.

Brazil provides valuable case studies for understanding potential solutions and challenges of accommodating new restoration areas where land is an increasingly limited resource (Latawiec *et al.*, 2015). The State of Espírito Santo government, supported by both agricultural and environment departments, has been promoting large-scale forest restoration and conservation programs through the 'Reforest' Program ('Reflorestar' in Portuguese) with a total goal of approximately 236 000 ha between 2005 and 2025. At the same time, the State's development plan aims to expand agricultural areas by 284 000 ha and forest plantations by 400 000 ha. The current pasture productivity in the State is less than one third of its potential (Latawiec *et al.*, 2015). Pasturelands therefore provide an opportunity to accommodate both intensified but non-confinement-based cattle ranching activities and restoration, through land sparing **(Figure Box 5.4.A)**.

A second example is from the state of Sao Paulo, where the Rural Landless Workers' Movement redistributed more than 3000 families to settle in the Pontal do Paranapanema in 1942, in the Reserva do Pontal area designated to protect the highly threatened Atlantic Forest ecosystem and the endangered endemic black lion tamarin (Hart *et al.*, 2016; Valladares-Padua *et al.*, 2002). A concerted effort by a range of stakeholders supported rural livelihoods through landscape-level coordination, developing sustainable agroforestry initiatives and creating ecological corridors to connect forest fragments (Wittman, 2010). Diversified agroforestry created a buffer for wildlife reserves and improved agricultural productivity, increasing incomes for local communities (Cullen *et al.*, 2005). This example demonstrates that implementation of a landscape approach wherein a participatory approach can facilitate forest conservation and restoration. Such integrated landscape management approaches have gained prominence in the search for solutions to reconcile conservation and development (Sayer, 2009), particularly if they consider nonlinear ecosystem dynamics and climate change (Sietz *et al.*, 2017).

Figure 5 4 A **An example of land sparing.**

An increase in pasture productivity in areas suitable for cattle ranching (left) allowed a farmer to set aside marginal areas with rocky soils (right) for forest restoration in the Atlantic Forest in Brazil (Latawiec *et al.,* 2015). Photo credit: Veronica Maioli.

These examples reveal several essential conditions for land sparing to occur, such as covering implementation costs, providing technical assistance, and setting up rigorous monitoring to avoid leakage and rebound effects. It is also paramount to protect local livelihoods involved in other farming activities that may be less profitable but key to meeting local and regional food security needs (e.g., production of staple crops such as black beans, in the case of Brazil). As illustrated by first São Paulo example, sometimes leakage might be best avoided by diversifying production systems through land sharing (Perfecto *et al.*, 2009).

Demand for agricultural land and land for restoration will continue to grow for several decades, putting pressure on scarce land resources (Smith *et al.*, 2010). This pressure can be mitigated, however, through solutions promoting more sustainable and inclusive land management. In particular, integrated land-use planning that takes into account conservation and restoration priorities with priorities for increased agricultural production (Margules & Pressey, 2000; Strassburg *et al.*, 2017) might play a key role in reconciling competing demands.

Conservation and restoration scenarios and IPLCs

Few of the aforementioned scenarios directly address the interplay between human well-being, nature conservation and restoration goals. It is primarily at local scales that studies suggest that engaging meaningfully with IPLCs—whose lands hold much of the world's biodiversity—is one of the most effective ways to secure biodiversity conservation and sustainable use (FPPIIFB & SCBD, 2006). The global importance of IPLCs is treated in chapters 1, 2, and 3.

Empowering IPLCs as central partners in conservation and climate-change mitigation has allowed many people to gain access to land and citizenship rights (chapters 3 and 6; Kohler & Brondizio, 2017), but this has provided limited improvements in access to social services and economic opportunities. On the other hand, Kohler and Brondizio (2017) suggest that public policies and conservation programs should not delegate responsibility for managing protected areas to IPLCs without considering local needs, expectations and attitudes toward conservation.

It is primarily at local scales that scenarios explicitly consider land tenure rights, economic incentives and alternatives, and vulnerability of IPLCs (living inside or outside protected areas and other special units; e.g., Folhes *et al.*, 2015). For example, in **China**, Cotter *et al.* (2014) considered a GoGreen scenario that embedded the MAB (Man and the Biosphere Programme) principles of conservation and sustainable livelihoods while introducing Traditional Chinese Medicine agroforestry. This GoGreen scenario enabled protection of forests while sustaining rural livelihoods. Similarly, Suwarno *et al.* (2018) concluded that the current forest moratorium policy (BAU) is not effective in reducing forest conversion and carbon emissions. Furthermore, they suggested that a policy combining a forest moratorium with livelihood support and increases in farm-gate prices for forest and agroforestry products could increase local communities' benefits from conservation (including via certification schemes for cocoa production). Elsewhere, Mitchell *et al.* (2015) employed social-ecological modelling and scenario analysis to explore how governance influences landscape-scale biodiversity outcomes in the **Australian Alps**. Their study highlighted the importance of shared values and attitudes supportive of conservation, as well as political will and strategic direction from local governments.

Finally, some scenarios also explicitly mention the importance of **using biodiversity products to create economic alternatives** for IPLCs and regional economies (Aguiar *et al.*, 2016; Folhes *et al.*, 2015). A recent paper (Nobre *et al.*, 2016) brings a broader proposal: a new development paradigm that transcends reconciling conservation with intensification of agriculture, moving towards biomimicry-based development—a "Fourth Industrial Revolution" that could benefit IPLCs and the world at large.

Synthesis and open questions about conservation and restoration pathways

The expansion of the current PA network is necessary to ensure that PAs are ecologically representative and connected, including in light of climate change. However, to accommodate conservation and restoration where land is increasingly limited, the reviewed literature points out that **participatory spatial planning based on a landscape approach** is key. The landscape approach aims to allocate and manage land to achieve social, economic, and environmental objectives in landscape mosaics where multiple land uses coexist. Such integrated management should also include the urban-rural interface, and the importance of locally desirable livelihood activities less profitable than industrial agriculture, but key to meeting local and regional food security needs.

On the other hand, many existing PAs are not effectively managed or adequately resourced. The review of the current scenario literature, especially at local to national levels, underlines the need to **protect the protected areas**, including by enhancing monitoring systems and legal frameworks.

Sustainable-use protected areas (and other special areas, such as indigenous lands) will rest upon **appropriate governance mechanisms and collaboration with IPLCs.** This would begin with recognition of IPLC knowledge and leadership including via novel compensation-oriented payments for ecosystem services programs (5.4.2.1), but it also might involve economic alternatives, technological innovations, and access to markets and basic services (education, health, etc.). On the other hand, IPLCs should not be seen as "traditional environmentalists" to whom the responsibility to manage protected areas is delegated, but rather an opportunity to co-govern with those who have intimate and ancestral-derived knowledge and practices, but also varying needs in different contexts. Finally, innovations related to the benign industrial use of biodiversity could benefit local populations and regional economies, and contribute to conservation.

Mechanisms to facilitate and scale up international **financing of protected areas** are also essential, especially in developing regions. However, funding is not enough, as weak governance and power structures in different regions need to be taken into account. **Power asymmetries**, especially in developing countries, threaten not only legal frameworks (for instance, regarding protected area networks), but also the possibility of implementing integrated management processes.

5.3.2.4 Maintaining freshwater for nature and humanity

Framing the problem

Maintaining freshwater for nature and humanity is an urgent challenge, with an estimated 1.8 billion people likely to live under conditions of regional water stress (Schlosser *et al.*, 2014). The diversion of freshwater for human use has been characterised by an incomplete appreciation of freshwater ecosystems and the services they provide. Aquatic ecosystems in some cases have been losing species up to 5 times faster than other ecosystems (Ricciardi & Rasmussen, 1999), and the situation is set to worsen as anthropogenic pressures on water resources increase (Darwall *et al.*, 2008; Dodds *et al.*, 2013; Dudgeon *et al.*, 2006). Anthropogenic land-cover change is a more dominant driver of hydrological impacts than climate change (Betts *et al.*, 2015), and global-scale population and economic growth variables have greater effects on projected water supply-demand relationships than does mean climate (Vörösmarty *et al.*, 2000). Climate change is a major driver of agricultural water demand, however, primarily through increased temperature, which increases the transpiration demand; effects due to changes in precipitation and runoff are variable and uncertain (Turral, 2011).

Around 2010, food production accounted for 70-84% of global water consumption, and dominated projected consumption (FAO, 2016; Secretariat of the Convention on Biological Diversity, 2014). Implementation of the OECD baseline scenario for 2050 in modelling biodiversity “intactness” of freshwater ecosystems (Janse *et al.*, 2015) indicates further global declines in aquatic species richness, particularly in Africa. In 2014, freshwater fish (a major livelihood component and economic sector) constituted 12.7% of the global capture fishery, and 64% of aquaculture fish (FAO, 2016; McIntyre *et al.*, 2016). Access to fish by IPLCs is being eroded by changing legal frameworks and commodification (Allison *et al.*, 2012; Beveridge *et al.*, 2013), as well as pollution and overfishing. Freshwater and associated fish are critically limiting resources on many small island nations. In the Polynesian islands, as one example, major threats to freshwater biodiversity relate mainly to alteration of natural flow regimes (barriers and abstraction of water), plus overharvesting, alien species and climate change (Keith *et al.*, 2013).

Water for energy production accounted for approximately 15% of global withdrawals in 2010 (Flörke *et al.*, 2013). Fricko *et al.* (2016) found that “once-through” cooling was the dominant source of withdrawals, and of thermal pollution in thermal power generation. Meeting targets for a stable global climate through the development of renewable energy puts additional stress on freshwater systems, because hydropower is considered a major renewable energy source. Changes in river flood pulses (sensu Junk, 1989) and water quality induced by dams have had adverse effects on biodiversity, ecological productivity (e.g., Abazaj *et al.*, 2016; Arias *et al.*, 2014) and sediment transport, by decreasing wet season flows, increasing dry season flows, impeding movement of aquatic life, and trapping sediments.

Changes in land cover in catchments affect river flow characteristics. Evidence for increased run-off from deforestation is clear (Zhang *et al.*, 2017), whereas the effects of afforestation are ambiguous (Jackson *et al.*, 2013; Vanclay, 2009). Clearly there are important trade-off implications for the carbon mitigation potential of afforestation. Land and terrestrial water management also poses a serious threat to the freshwater-marine interface (Blum & Roberts, 2009). Lotze *et al.* (2006) analysed 12 temperate estuaries and coastal seas, and found that about 40% of species depletions and extinctions could be attributed to habitat loss, pollution, and eutrophication. Other important consumers of water are industries, of which mining is particularly important in terms of demand and impacts (pollution, sediment load; Azapagic, 2004; Vörösmarty *et al.*, 2013; chapter 2).

Here we summarise characteristics of pathways towards resolving these tensions and challenges at global, regional and local levels, and draw out commonalities and differences across these scales. People use water to supply domestic and urban needs, to produce food, and to produce energy. These uses consume water, change its quality, and change associated contributions to people. Most normative scenarios relating to water have focused on improving water supply and quality for human purposes. In recent years, freshwater policies “have begun to move away from a riparian rights focus … towards efficiency improvements and river basin management” (UNEP, 2002). At the global scale, this shift is reflected in the global scenario analyses, as outlined below.

What do scenarios say about how to achieve these goals?

The GEO-3 “Policy First” scenario (UNEP, 2002) emphasizes using top-down governmental policy and institutional instruments to create integrated resource management approaches, including increased environmental stewardship. This scenario also invests in governance focused on social environmental policies, and enables greater participation from the private sector. The “Sustainability First” scenario describes pathways grounded in both government and civic society taking action against declining global social, economic and environmental indicators. The pathways incorporate greater collaboration between actors, with initiatives from society pushing sustainability. They also rest on positive media engagement, incorporation of research and analysis, and increased accountability and transparency. Greater integration of regional policies related to water management and other transboundary issues are envisioned.

The GBO-4 (CBD, 2014) re-assessment of the PBL (2012) Roads from Rio+20 used the same 3 scenarios designed to attain SDG targets, but with metrics addressing Aichi Biodiversity Targets relating to inland waters. Elements of all three scenario pathways address the maintenance of freshwater ecosystems and their multiple contributions. Aside from the systemic integration of freshwater nature into planning, development and communications, GBO-4 pathways include national accounting of water stocks. Specifically, in these pathways IPLCs are involved in creating and governing protected areas (PAs), PA networks are expanded to be more representative of freshwater ecosystems, and protection is enhanced for river reaches upstream and downstream of terrestrial PAs to maintain connectivity. These pathway elements were echoed strongly by Harrison *et al.* (2016). GBO-4 included a range of other elements, including management of pulsed systems that protects refugia for aquatic biota, identification of systems important for providing multiple ecosystem services (including disaster risk reduction); reduction of pressures on wetlands, river and mountain areas, and restoration of degraded systems. Policy instruments include the enforcement of environmental regulations for development projects, and new market instruments (wetland mitigation banking, payments for ecosystem services).

Pathways for food and freshwater

Pathways towards sustaining freshwater ecosystems and their multiple contributions rest on addressing **land use**, **eutrophication** and **hydrological disturbance**. The World Water Vision (Cosgrove & Rijsberman, 2000) identified two critical pathway elements: 1) limiting expansion of agricultural land area (requiring improved water use efficiency and agronomy) and 2) increased storage, through a mix of groundwater recharge, wetlands, alternative storage techniques employing ILK, and dams that minimize disruption of flow regimes and impacts, including on IPLCs.

Pathways for energy, climate and freshwater

Fricko *et al.* (2017) found significant potential gains from technological improvements in cooling. Transitioning toward air and sea-water cooling over the period 2040-2100 could reduce cumulative freshwater withdrawal by 74%, consumption of freshwater by 19% and thermal pollution by 41%. In addition, a rapid scale-up of non-water based renewable energy generation (wind, solar) could generate multiple co-benefits, including climate stabilisation, reduced water demand, improved water quality and a reduction in hydrological disturbance, sustaining fluvial ecosystems. In the Gulf States, cogeneration (using thermal energy from electricity generation to desalinate seawater) is responsible for about 85% of desalination (El-Katiri, 2013).

Flow alteration and barriers were not explicitly addressed in the global scenario pathways assessed here. At local and regional scales, studies suggest that improving environmental legislation (Fearnside, 2015), enhancing existing infrastructure (Zwarts *et al.*, 2006), and implementing operating procedures to minimise downstream ecological impacts (Kunz *et al.*, 2013) are critical pathway elements for conserving freshwater systems and their contributions. Demand management (advocated in GEO-3 and other meta-analyses) is also a central recommendation, including improved water use efficiency, pricing policies and privatisation.

In freshwater system pathways, there are some synergies between conserving nature and NCP and mitigating climate change: restoring and avoiding further conversion of peatlands is an important pathway element (Griscom *et al.*, 2017).

Regional and local perspectives

Sub-Saharan **Africa** is expected to experience one of the largest increases in point-source pollution of freshwater due to increasing urbanization and slow development of sewage treatment (Nagendra *et al.*, 2018). Investment in wastewater treatment is crucial to complement improved sewage reticulation (van Puijenbroek *et al.*, 2015), while investment in distribution infrastructure and improved regulation of access are pathway elements to ensure equitable access to water (Notter *et al.*, 2013).

Improvement of infrastructure across the continent is needed to increase agricultural production, while improved irrigation efficiency needs better enforcement of regulations (AfDB, 2015; Notter *et al.*, 2013). In the Inner Niger Delta, Zwarts *et al.* (2006) found that improving efficiency of existing water infrastructure, instead of building new dams, would improve conservation of ecosystem services and economic growth. In southern Africa a number of studies indicate that participatory approaches to water resource planning and environmental flows could enable equitable trade-offs between water users (Brown *et al.*, 2006; King *et al.*, 2014, 2003). Operating procedures for existing hydropower dams can be optimised to reduce biogeochemical impacts downstream (Kunz *et al.*, 2013).

In the Americas, issues arising from hydropower developments have identified elements of pathways towards sustainability (Moran *et al.*, 2018). In the Brazilian Amazon, unrepealed legacy legislation has allowed the overriding of environmental licensing laws; institutions and legal instruments, and full disclosure and democratic debate on river basin development plans are critical pathway elements, especially for transboundary river systems (Fearnside, 2015; Latrubesse *et al.*, 2017). At the local level in the Brazilian Amazon, key pathways include strengthening the capacity of local communities to negotiate with developers and develop management skills for collective projects (Folhes *et al.*, 2015).

Social-ecological systems modelling by Mitchell *et al.* (2015) in south-eastern Australia in the **Asia and the Pacific** region indicates that conservation of alpine lakes, fens and bogs would be enhanced by adoption of a long-term governance regime immune to short-term political agendas.

In **Europe and Central Asia**, a participatory backcasting scenario planning process for Biscay in the Basque Country found that water supply and water regulation could be optimised under their "TechnoFaith" scenario—one which prioritizes technological solutions. The "Cultivating Social Values" scenario achieved almost the same results through participatory decision-making, emphasis on local government, responsible consumption, and a proactive society (Palacios-Agundez *et al.*, 2013).

Synthesis about freshwater pathways

The scenarios literature reviewed above coupled with broader literatures on freshwater systems and management suggest the following key elements of sustainable pathways. A central cross-cutting conclusion is that sustenance of freshwater ecosystems and their contributions requires healthy catchment areas, careful allocation of water rights and maintenance of hydrologic variability (Aylward *et al.*, 2005; Dudgeon, 2010; Durance *et al.*, 2016; Harrison *et al.*, 2016; Kuiper *et al.*, 2014; Poff, 2009; Postel & Thompson, 2005). **Foremost among pathway elements is the importance of dynamic and iterative deliberations among stakeholders** in identifying desired futures and policy to achieve these (Tinch *et al.*, 2016).

Freshwater production as an ecosystem service: The pathways reviewed secure sustained supply of good quality water sufficient for human and environmental needs. This requires protection of upstream catchment areas, middle-reach floodplain systems (Green *et al.*, 2015) and often land rehabilitation to reinstate storage and reduce erosion and sediment transport. Such efforts can be broadened to regional and continental institutional arrangements to address the impacts of land-use change at basin scales (Ellison *et al.*, 2017). Explicit recognition of the provisioning function of upstream catchments is crucial for land-use planning, a central element of sustainable pathways. Design strategies for forested catchment land cover, such as (re)planting water courses with indigenous species can also produce natural hydrographs and high-quality water (Ferraz *et al.*, 2013; Vanclay, 2009). Integration of surface and groundwater management (Giordano, 2009) reduces the need for dams. Catchment protection (e.g., limiting mining and industry) can reduce pollution of water-producing areas.

Freshwater systems: There is strong consensus that variability in hydrological regime is crucial for maintaining freshwater ecosystems and their contributions to society, as central in sustainable pathways (e.g., Annear *et al.*, 2004; Biggs *et al.*, 2005; Bunn & Arthington, 2002; Poff *et al.*, 1997, 2010; Postel & Richter, 2003). Sustainable pathways maintain or re-instate flow variability, quantity, timing and quality needed to sustain healthy freshwater systems. Pathway element include: i) slowing and reversing catchment land cover transformations (deforestation, intensive cultivation); and ii) minimising disruption of flow regimes by using fewer, smaller dams.

Agricultural production: Attaining ambitious pathway targets for agricultural production (see section 5.3.2.1 Feeding Humanity) without damaging freshwater nature entails a broad set of actions. Optimising water use for agricultural production rests on sustainable intensification, improved management through technology, better agronomy, and improved hydrological governance, including implementation of "green water" techniques (Bitterman *et al.*, 2016; Pandey *et al.*, 2001; Rockström & Falkenmark, 2015). Also important are improved management to reduce non-point source pollution (e.g., Hunke *et al.*, 2015) and sediment input to freshwater systems, and enforcement of standards and allocations.

Energy production: The production of hydropower—central to many sustainable pathways—carries many impacts which cannot be mitigated (e.g., Fearnside, 2015; Kling *et al.*, 2014). Reductions in variability, discharge and changes in biogeochemistry are among these. Alternative sources of renewable energy are implementable with present technology. Management regimes of existing hydropower dams can be optimised by integrating ecological requirements of variability and water quality into standard operating protocols (Kunz *et al.*, 2013).

Supply chains: Sustainable pathways require that supply chains secure sufficient water to meet environmental demands, human rights and needs. This can be achieved by a combination of improved valuation of the resource (demand management), involving stakeholders inclusively, and investment in infrastructure, such as dual reticulation systems for urban supply, treatment systems for urban waste water and agricultural waste water. Dedicated institutional arrangements for managing river basins are seen as a critical component for managing supply chains.

Consumer actions: Reduction of consumption and waste as a key pathway element can be achieved by optimising efficiency in urban use, agricultural use (precision irrigation, improved agronomy, reduced waste flows), industrial/mining use (tertiary treatment of waste, increased regulatory oversight) and the energy sector (transition to alternative renewables, and cooling systems). Such actions are not likely to be made without changing incentives (including water pricing) (5.4.1.1, 5.4.2.1), encouraging behaviour change including through infrastructure (5.4.1.3), and increasing awareness and knowledge among consumers (5.4.1.8).

5.3.2.5 Balancing food provision from oceans and coasts with nature protection

Framing the Problem

Seafood from fisheries and aquaculture is an integral part of the global food system, supplying approximately 17% of all animal protein consumed by humans and providing a suite of micronutrients important for human nutrition (FAO, 2016). The dietary importance of seafood is pronounced in many food-insecure regions (Béné & Heck, 2005; FAO, 2016). Demand for seafood is predicted to grow substantially in coming decades, potentially at a higher rate than other major sources of animal protein (Tilman & Clark, 2014), and failing to meet that demand may affect the health of millions of people (Golden *et al.*, 2016).

Broad limits to global marine fisheries production have been reached (Worm & Branch, 2012), while aquaculture production of aquatic animals has steadily increased over the past four decades. As of 2013, 31.4% of fish stocks evaluated by the FAO were determined to be overfished and 58.1% were fully fished (FAO, 2016); the former yield less food than is theoretically possible, and the latter cannot yield additional food without becoming overfished. While marine fisheries landings reported by the FAO have remained relatively steady since the mid-1990s, at ~80 million metric tons, aquaculture production increased from less than 10 million tons in 1985 to over 70 million tons, or 44% of the world's total seafood production, in 2014 (FAO, 2016). A recent reconstruction of global catches (including catch types excluded from the FAO data) indicate that the mid-1990s global maximum in catches was higher, and that the decline in the subsequent years has been more severe, than observed in the FAO data alone (Pauly & Zeller, 2016). While aquaculture avoids some of the ecological concerns of fisheries, concerns involve the conversion of coastal wetlands, particularly mangroves, for aquaculture (Ottinger *et al.*, 2016), and the use of the majority of the world's fish oil and fishmeal production for aquaculture feeds (Tacon & Metian, 2015).

Safeguarding and improving the status of biodiversity will entail reducing intensity of seafood production to levels that allow for sustainable use of living marine resources (Sumaila *et al.*, 2015; Worm *et al.*, 2009). Some efficiency improvements are possible, however, such as ensuring that food-grade fish are used for direct human consumption rather than for aquaculture or livestock feed (Cashion *et al.*, 2017). While indirect drivers such as demographic changes and consumption patterns increase pressures on marine biodiversity, these drivers also exacerbate other factors such as poor governance and poverty (Finkbeiner *et al.*, 2017). When fisheries resources are overexploited, actions to improve conservation status can also increase sustainable seafood production. However, conservation and fisheries rebuilding may affect the availability and access to living marine resources by specific human communities in the short-term, although effectively managed marine ecosystems can support long-term sustainable development (Costello *et al.*, 2016; Jennings *et al.*, 2016; McClanahan *et al.*, 2015). Involvement and participation of stakeholders and local communities and consideration of local traditions in decision-making and implementation of resource management and biodiversity conservation policies could help reduce trade-offs between seafood provision and biodiversity conservation (Berkes, 2004; Christie *et al.*, 2017; Uehara *et al.*, 2016). Meeting food provisioning objectives appears to entail conservation and/or restoration of marine ecosystems, reduction of pollution, management of destructive extractive activities, strong progress toward climate change targets, elimination of perverse subsidies, education and other aspects of capacity builiding (Teh *et al.*, 2017).

What do scenarios say about how to achieve these goals?

Available scenarios for marine biodiversity and ecosystem services focus on identifying and exploring pathways to achieve biodiversity conservation and sustainable seafood production goals across multiple spatial scales (Table SM 5.2.A). Specifically, these scenarios explore options for marine protected areas and fisheries management such as spatial planning and control of catches or fishing effort. Climate change and its effects on marine biodiversity and ecosystems are included in a few cases to examine how regional conservation and fisheries management goals can be achieved under global changes.

Marine pollution is a cross-cutting issue that is often implicitly included in scenarios related to multiple economic sectors. Some of these sectors are sources of marine pollution. Marine spatial planning processes are central, managing activities such as shipping and coastal development. With recent focus on plastic waste in the ocean (e.g., see chapter 4), scenarios have been developed for waste management to achieve targets for marine plastic waste (Löhr *et al.*, 2017). A variety of telecouplings were explored particularly in management of transboundary fish stocks (Carlson *et al.*, 2018). For example, different fisheries management measures in the high seas on straddling fish stocks were examined to investigate their effectiveness in reducing climate risk on coastal fisheries and biodiversity (Cheung *et al.*, 2017).

Regional to global scale scenarios often focus on examining a specific policy pathway, while multiple pathways are more commonly considered at subnational to national scales (Table SM 5.2.A and Figure SM 5.2.A). At large spatial scales, existing scenarios explored different extents and configurations of marine protected areas and their effectiveness in protecting biodiversity from impacts of multiple human activities, or management of fishing effort to maximize sustainable seafood production. Although these scenario pathways are not considered simultaneously, they may indeed be mutually compatible in comprehensive pathways to sustainability. In contrast, scenarios for smaller spatial scales often examine pathways to specific national or regional policy frameworks such as the Marine Strategy Framework Directive in the Europe Union or, more generally, ecosystem-based management. These policy frameworks involve multiple policy goals, e.g., biodiversity conservation, economic benefits, sustainable food production, and the viability of specific industries or sectors. Examining a portfolio of pathways and options to achieve these multiple policy objectives and their associated interactions and trade-offs could help inform ecosystem-based management of the ocean.

One of the linkages between marine biodiversity and sustainable food production goals that is most commonly explored in existing scenario analyses (specifically target-seeking/policy-screening) is pathways to achieve Maximum Sustainable Yield (MSY) and the implications for biodiversity (see 5.3.2.5). Although direct utility of MSY as a target for fisheries management has been widely criticized (Berkes *et al.*, 1998), MSY is explicitly stated as an aspiration in important international agreements and national policies such as the United Nations Law of the Seas and and the European Common Fisheries Policy. However, achieving ecosystem-level long-term average maximum production may lead to overexploitation or depletion of relatively less productive or less valuable populations (e.g., through bycatch), which has been suggested in scenario assessments at global, regional and local scales (Cheung & Sumaila, 2008; Walters & Martell, 2004; Worm *et al.*, 2009). In some heavily exploited systems, achieving maximum sustainable yield may require restoring ecosystems and rebuilding fish stocks, which would have co-benefits for biodiversity conservation (Cheung & Sumaila, 2008; Pitcher *et al.*, 2000). In some specific cases, overexploitation has resulted in structural change in fisheries social-ecological systems, resulting in more intense trade-offs between maximizing sustainable yield and improving biodiversity status (Brown & Trebilco, 2014; Hicks *et al.*, 2016). For example, in eastern North America, the rise of invertebrate fisheries (e.g., shrimp) after the collapse of Atlantic cod may be due to a shift from a predator-controlled system to a prey-controlled system (Baum & Worm, 2009). Because of the high productivity and economic value of the invertebrates, rebuilding of cod fisheries (a potential biodiversity or ecosystem target) may lead to reduced fisheries profits (a sustainable food production target).

Achieving marine protected area (MPA) targets should contribute positively to both biodiversity conservation and sustainable food production, although the extent of co-benefits would depend on timeframe, site selection, and design and effectiveness of the protected areas. Scenario modelling efforts for MPA targets focus strongly on site selection with a primary objective of biodiversity conservation. Across many contexts, scenario and modelling studies that evaluate different MPA designs and the pathway to achieving MPA targets generally suggest that MPA networks would benefit both biodiversity and fisheries in the long-term, particularly in overexploited ecosystems, in part because of demonstrated spillover effects by which effectively-managed MPAs boost fisheries in surrounding waters (Gill *et al.*, 2017). However, trade-offs often exist in the short-term because of the time lag in biological responses to protection relative to the immediate cost of losing resource use opportunities (Brown *et al.*, 2015). The degree of such trade-offs and co-benefits is shown to be sensitive to ecosystem and MPA attributes such as mobility of organisms, dispersal of the populations, size of and connectivity between protected areas (Gill *et al.*, 2017). In addition, scenario analysis, particularly those with stakeholders participation, often reveals trade-offs and conflicts between different sectors and communities in identifying pathways to achieve the MPA targets (e.g., Daw *et al.*, 2012). Climate change may further complicate the trade-offs between MPA designation and different sectors as range-shifts and habitat changes driven by climate change may add additional constraints on the design of

MPA network or require bigger MPAs (Fredston-Hermann *et al.*, 2018). On the other hand, scenario analysis at multiple scales could also help identify pathways to reduce or resolve such trade-offs (IPBES, 2016).

Scenario research has also identified co-benefits from addressing other non-fishing drivers such as climate change (and ocean acidification) and habitat degradation. Given the increased focus on ecosystem-based fisheries management (Link, 2010), recent scenario analyses explored multiple drivers that cut across marine biodiversity and sustainable food production, including environmental change drivers (e.g., climate, pollution and habitat degradation). Overall, clear co-benefits exist in addressing drivers of environmental change for both biodiversity conservation and fisheries production globally (e.g., Cheung *et al.*, 2016) and regionally (e.g., Ainsworth *et al.*, 2012; Sumaila & Cheung, 2015). Specifically, climate change is likely to trigger species turnover and decreased potential fisheries catches, which compromises both biodiversity conservation and food production (Cheung *et al.*, 2009; Worm *et al.*, 2009).

Resolving apparently competing targets in sustainability pathways appears to require other actions with co-benefits for each. For instance, addressing perverse incentives associated with subsidies is a key element of sustainable pathways, given its co-benefits for biodiversity and long-term food provision (Pauly *et al.*, 2002; Sumaila *et al.*, 2010). Outside of fisheries management, organic and inorganic pollution are doubly harmful, often leading to hypoxia and increased harmful contaminants in seafood (e.g., mercury). Thus, achieving targets that address these climate and pollution drivers is an important element towards achieving both biodiversity and food security targets. However, few scenario analyses explore the contributions of mitigating these drivers for achieving biodiversity and fisheries targets. This is particularly relevant for climate change mitigation given that reducing biodiversity loss and/or ensuring sustainable food production (e.g., by eliminating overfishing, protecting habitat, and protecting local access to seafood) could be cost-effective means to reduce the impacts of climate change (Gattuso *et al.*, 2015).

Synthesis and open questions about pathways for oceans

Conservation and restoration of marine ecosystems can contribute positively to meeting food security goals in the long-term (Singh *et al.*, 2018). Marine conservation includes effective management of fishing and other extractive activities, consideration of climate change mitigation and adaptation, and reduction of pollution and other human pressures on marine ecosystems. International conventions and agreements exist to facilitate the development of specific actions at regional and national levels to achieve specific conservation targets and goals (Rochette *et al.*, 2015). Ultimately, a portfolio of measures is often key to reduce pressures on marine ecosystems (Edgar *et al.*, 2014).

Scenarios rarely consider explicitly the co-benefits and interactions between meeting conservation and food security goals, particularly for vulnerable coastal communities (McClanahan *et al.*, 2015). Recent studies, mainly at regional to local scales, have started to explore conservation-food security interactions using scenario analysis **(Table SM 5.2 A)**. Initiatives are underway to further develop capacity for scenarios and models for marine biodiversity and ecosystem services, including collating global and regional datasets for drivers such as fisheries catch and oceanographic changes, e.g., the Fisheries and Marine Ecosystems Impact Model Intercomparison Project (Tittensor *et al.*, 2018). Specific actions being considered in pathways to achieve both conservation and food security goals include, for example, elimination of perverse subsidies, reduction in fishing capacity, alternative fisheries management, designation of marine protected areas and climate mitigations. However, given the increasing focus of international conservation efforts on large marine protected areas or co-management of natural resources beyond national jurisdictions, linking scenario exercises with global scale pathways would help elucidate co-benefits and trade-offs of conservation efforts with food security issues locally, nationally and globally.

5.3.2.6 Resourcing growing cities while maintaining the nature that underpins them

Framing the problem

Urbanization rates, while relatively stable within developed country contexts, are increasing at an unprecedented scale within developing countries of the Global South (CBD, 2012; Nagendra *et al.*, 2018). Urbanization is both the movement of people from rural to urban areas, and a function of population increases within these regions. Urban dwellers now exceed 50% of the global population, and by 2050, there will be 2 to 6 billion more of them (UN, 2012). Urbanization will drive land-cover change both within defined city boundaries and in the broader surrounding landscapes from which cities are resourced. City expansion into surrounding areas is happening more rapidly in developing countries, and population growth appears to be a key driver here. In developed country contexts urban growth and expansion is slower and more strongly correlated with GDP measures and economic growth (Seto *et al.*, 2011). Cities are major consumers of natural resources and are highly reliant on regulating functions provided by ecosystems. These resource and ecosystem dependencies can stretch over extensive areas and form the basis of telecoupled systems where trade flows of resources connect distant regions (Fang *et al.*, 2016). And despite trade flows, cities face real challenges to maintain crucial resources, including clean water (Schlosser *et al.*, 2014).

Rapid urbanization is driving extensive changes in land cover and land use. This landscape fragmentation alters biodiversity patterns and ecosystem functions (Aronson *et al.*, 2014; Foley *et al.*, 2005; McKinney, 2006; Miller & Hobbs, 2002). Growth within and on the margins of cities can overlap with areas of rich biodiversity and natural resources (Chapin III *et al.*, 1997; McDonald, 2008; Ricketts & Imhoff, 2003). Rapidly urbanizing cities in biodiversity hotspots (such as Cape Town, South Africa) are particularly vulnerable to extinction and loss (Holmes *et al.*, 2012; Seto *et al.*, 2012a).

There is a pressing need to understand the implications of loss of species and habitats in and around cities (Grimm *et al.*, 2008), in terms of ecosystem services, human well-being and equity issues. How cities are provisioned with ecosystem services now and in the future relates to the success reaching the SDGs, particularly SDG 11 (to make cities inclusive, safe, and resilient and sustainable) and SDG 15 (protecting, restoring and promoting the sustainable use of terrestrial ecosystems).

What do scenarios say about how to achieve these goals?

Local scenarios and pathways related to nature, urbanization and sustainable development

A wealth of biodiversity can exist in cities (CBD, 2012), which is important for human health and well-being, livelihood opportunities, heat mitigation, and spiritual and cultural values. Developing in a manner that secures this can be extremely difficult to achieve in cities with high levels of endemic biodiversity and pressing social needs, such as housing (e.g., Cape Town, South Africa; O'Farrell *et al.*, 2012). Informality, witnessed through sprawling collections of informal dwellings, is one such key issue and characterises rapid urbanization observed across the Global South. The widespread presence of informality highlights the local realities of poverty, a lack of urban planning and the limited capacity to shape local landscape outcomes. Schneider *et al.* (2012) note the importance of understanding local ecology in determining the role and the impact of urban form both within the city and beyond it. Their work speaks specifically to urban density, water and food relationships, and shows the negative impacts of urban sprawl for biodiversity, productivity, and local ecology. Güneralp *et al.* (2013) note the local impacts of shifting towards meat-based diets within urbanizing areas.

The Cities and Biodiversity Outlook (CBD, 2012) highlights the importance of local knowledge in underpinning urban planning and resource management. Ahrends *et al.* (2010) produced models that demonstrate the role of markets on the degradation of resources within an African city context. Weak governance fails to secure the integrity of local biodiversity resources, allowing continued erosion of public goods. Detailed place-based knowledge and modelled futures around urban projections (Güneralp & Seto, 2013) can be used to inform appropriate local policy development pathways towards sustainable futures. These should include a detailed understanding of infrastructure, incentives and disincentives to promote benign development patterns that simultaneously promote conservation. Contemporary local form in many cities presents opportunities for land managers and decision-makers to improve urban design. Combined with a systemic understanding of nature and its contributions to people, this will allow for effective sustainable planning.

One pivotal policy domain with likely long-term impact on future scenarios relates to the initial choice about local and regional road network structures (Barrington-Leigh & Millard-Ball, 2017; Marshall & Garrick, 2010; Seto *et al.*, 2014). This choice about the configuration and location of road networks is a near-permanent commitment, as compared with other aspects of physical urban form and urban land use. Road networks underlie and constrain all other aspects of urban form, which in turn affect GHG emissions, energy intensity, community activities, and resource use through travel, consumption, extraction and home production patterns (Barrington-Leigh & Millard-Ball, 2015). In addition, high-connectivity, grid-like road networks are conducive to high-density settlement, while low-connectivity road networks are highly resistant to densification. Ensuring all new road networks are highly connected will impact the extent of habitat loss during late phases of urbanization. Prominent ongoing trends in transportation infrastructure present both threat and promise for resource impacts of cities. The electrification of transport promises higher efficiency (lower resource use) but possible rebound (more travel and sprawl). Automation of transport may exacerbate preferences for low-connectivity street-network sprawl, but may also encourage vehicle sharing and free up the large fraction of city space currently used for parking, providing opportunities for improving and reimagining use of urban space.

Regional scenarios and pathways related to nature, urbanization and sustainable development

Regional trends and informants: While urban land-cover area is set to increase, how and where urban areas will expand remains unclear. Work by Seto *et al.* (2012a) on regional influences shows that population growth, international capital flows, informal economies, land use policies, and transportation costs are all important driving factors. These influencing factors vary regionally with variable outcomes, however the regions of greatest anticipated urban expansion are Africa (particularly sub-Saharan), Asia and Latin America. Regional understandings show some shared trends, but also regional variance. Expansion in Africa is likely to emerge in the form of growth in smaller towns, while Asia shows tight coupling between urban expansion and economic shifts, and in Latin America urbanization is characterised by persistent socio-economic disparities (CBD, 2012). In contrast some regions of the Global North are experiencing urban depopulation. In their analysis of national and regional models relating to food production and urban expansion, Nelson *et al.* (2010) found variable impacts on biodiversity and ecosystem services, with various influences and trade-offs at different scales, highlighting the need to consider regional effects in local decision-making and vice versa.

Regional threats to biodiversity

Scenario modelling exploring the relationship between urbanization and protected areas and biodiversity hotspots shows alarming encroachment by cities into these key biodiversity areas, with regional variation. Güneralp and Seto (2013) tracked and modelled urban growth and demonstrate that urban areas are increasing in proximity to protected areas. McDonald *et al.* (2008) reiterate this finding and serve to refine the distances and related impacts between growing cities and adjacent, previously distant, protected areas. The most rapid urban expansion in relation to adjacent protected areas is found in China, while in South America rapid urban expansion also threatens biodiversity hotspots (critical biodiversity areas without formal protection status). Forecasts consistently show overlaps between predicted areas of rapid urban expansion and intact natural habitat and biodiversity, with protected natural assets experiencing increased pressure (McDonald *et al.*, 2008). Also evident here is the variation in regional conservation approaches. Landscape perspectives are required and in this respect we can learn much for scenario modelling from both agriculture and conservation science (Schneider *et al.*, 2012).

Global scenarios and pathways related to nature, urbanization and sustainable development

Linking urban form to sustainable development

Modelled urban scenarios show likely global trends where urban land cover expansion exceeds urban population growth, highlighting the importance at the global scale of considering biodiversity management as an imperative in urban planning. Scenarios by Fragkias *et al.* (2013) suggest that between 2000 and 2030 a 70% increase in urban population will be matched by a startling 200% increase in urban cover, and that 50% – 60% of the total urban cover in 2030 will be built post-2000. McDonald (2008) makes the incontrovertible connection between urban form and per capita resource consumption, demonstrating that urbanization has profound and prolonged implications for oil consumption and climate change, such that new urban design is critically important. Ever-improving understanding of the relationships between existing urban forms and biodiversity can be effectively used to guide future urban design and development for improved sustainability.

Economic flows and telecouplings

It is increasingly recognized that global economic forces play a significant role in determining local urban form and land-cover change. In their footprint analysis, Folke *et al.* (1997) demonstrate how Baltic cities are embedded in a web of connections that stretch far beyond their own immediate environment. These cities from the Global North import and consume from distant regions without a sense of the associated ecological impacts. Folke *et al.* (1997) go on to argue that the economic forces that govern these telecouplings fall beyond the sphere of influence of ordinary citizens. Telecouplings between cities and other areas are very common, as through the provision of water and other resources (Deines *et al.*, 2016; Liu *et al.*, 2015b; Seto *et al.*, 2012b; Yang *et al.*, 2016). The flow of financial capital itself in the form of tax havens is responsible for fuelling much distant environmental degradation, including illegal fishing (Galaz *et al.*, 2018). Understanding telecouplings can help develop appropriate policies that are more equitable and just towards pathways for sustainability (Schröter *et al.*, 2018).

Synthesis and open questions about pathways for cities

The scenarios literature reviewed above coupled with broader literatures on city impacts and ecosystem services suggest the following key elements of sustainable pathways. A central element of sustainable pathways for cities (as in SDG 11) is maintaining nature and its contributions to people within cities and their broader regions (Folke *et al.*, 2009; Russell *et al.*, 2013), and broad access to those contributions, recognizing the multiple and diverse values of city residents (Pascual *et al.*, 2017a). To achieve sustainable development objectives within cities and ultimately develop sustainable cities requires critical engagement across multiple sectors, and a keen understanding of the challenges and action required at local, regional and global scales (Schröter *et al.*, 2018).

At local scales, city-specific thresholds are crucial for retaining species and ecosystem, and for pathways to achieve acceptable levels of urban transformation (CBD, 2012). This is especially difficult in biodiversity-rich areas in developing city contexts (O'Farrell *et al.*, 2012). Linked to this are the needs to strengthen local governance in order to secure public goods, and to enable transdisciplinary planning at local levels such that sectors and departments are bridged and society and businesses are engaged. Such engagements appear fundamental to shaping sustainable urban areas and guiding local-level resource consumption patterns (CBD, 2012).

Facilitating the local realization of global targets for sustainable urban development entails recognizing the emergent differences between and within regions, and the drivers of these (Seto *et al.*, 2012a). Several drivers are key: economic policy and processes, financial underpinnings, infrastructure, investment, and population growth (Seto *et al.*, 2012a). An understanding of how these key drivers impact biodiversity areas (such as protected areas) would be instructive. In particular, cities can work to ensure that biodiversity areas do not become isolated through incompatible surrounding land uses, and that city expansion considers the degree to which encroachment towards these key regional biodiversity sites can be tolerated (Güneralp & Seto, 2013).

Cities play a central role in global pathways because increasing urban land cover affects consumption of resources, including fossil fuels, which in turn propel climate change (Fragkias *et al.*, 2013). Efforts to follow sustainable development pathways within urban areas will thus benefit from a clearer understanding of telecouplings that drive patterns of production, consumption, transportation and disposal, which in turn create and entrench the spatial and social configurations of our cities. This global understanding can then in turn be used to guide local level policy formulation where negative effects are countered and where functioning ecosystems are enhanced alongside their contributions to people (Schröter *et al.*, 2018).

5.3.3 Conclusions from the scenario review

The nexus-based analysis has revealed that no single strategy will yield sufficient transformation to sustainable development and achieve multiple SDGs. All foci suggest that successful pathways entail various measures and instruments applied in concert at local, regional and global scales. All six foci involve trade-offs between sectors and groups, such that compromises are inevitable as conflicting objectives are balanced. However, the six foci also identify potential synergies where some actions have benefits across multiple objectives and for many groups. Here we synthesize five cross-cutting insights from the scenario review, which structure section 5.4 on constituents of pathways to sustainability and are taken up also in the discussion of policy options in chapter 6.

Consumption patterns are a fundamental driver of material extraction, production, and flows, but they too are driven—by worldviews and notions of good quality of life. Addressing aggregate consumption is a central theme in pathways for all foci, but some aspects are more explicit in some than others. For example, although it is aggregate consumption that drives resource extraction and production, research on scenarios and pathways more commonly addressed per capita consumption and waste than population. Similarly, scenario studies quite commonly mentioned the preferences, value systems, and (less often) collective notions of a good quality of life as drivers of consumption, but these aspects were generally not modelled explicitly (See 5.4.1.1 about visions of a good quality of life, and 5.4.1.2 about consumption).

Behaviour change pervades all aspects of transformative change—supply chains and their ecological degradation, but also conservation and restoration. Consumption is effectively a problem of habits and behavioural norms, but so too are changes in practices of production (e.g., agroecological practices in farming), conservation and restoration. All six foci identified such behaviour change as central, but scenario studies varied greatly in the detail with which they envisioned enabling this change. Many studies appealed to a combination of incentives and awareness raising, even though the latter is generally regarded to be a weak enabler of behaviour in relation to infrastructure and consistency with value systems (See 5.4.1.3 about values, agency, and behaviour).

Inequalities and inclusiveness are key underlying problems—good planning helps, but power disparities remain an issue. Across the six foci, many studies highlighted the crucial importance of addressing inequalities and involving people in participatory planning, including the urban poor and Indigenous Peoples and Local Communities. But only a few really addressed the barriers to transformative change that arise from substantial inequities in power, e.g., in the food system, where studies highlighted the difficulties posed by corporate control of seeds, agricultural inputs, and food distribution. The same issues are likely equally important in other foci, e.g., industrial fishers and seafood distributors, but were not discussed explicitly in the studies we found (See 5.4.1.4 about inequalities, and 5.4.1.5 about inclusiveness in planning and conservation).

Larger structural issues underpin all of the above factors—telecouplings, technology, innovation, investment, education and knowledge transmission. Key elements of these structural factors were often largely implicit in pathways analyses, despite their fundamental importance to behaviour change, the dynamics of global social-ecological systems, and the SDGs. The distant effects of local actions caused by telecouplings were central to the cities focus, and implicit in all of the others (e.g., via spatially disjunct supply and demand). Many studies across several foci discussed the potential gains from the spread of beneficial technologies (e.g., the climate mitigation focus), but fewer directly addressed the challenges posed by spread of harmful technologies, or the importance and design of innovation systems that encourage benign technology. Education and knowledge transmission were often addressed in scenarios directly in the form of awareness raising for particular behavioural changes or technology transfer, leaving mostly implicit the crucial roles of education systems for ensuring well-functioning participatory processes (including political ones), and of the transmission of ILK for maintaining local capacities for stewardship (See 5.4.1.6 about telecoupling, 5.4.1.7 about technolgy, innovation and investment, and 5.4.1.8 about education and knowledge transmission).

Sustainability pathway analyses indicate the importance of governance instruments and approaches such as incentives, adaptive management, law and its enforcement. There was near universal acknowledgement of the importance of several governance instruments and approaches, but much more attention to some aspects than others. For example, many studies across all foci appealed to the importance of economic incentives, but generally from a simple behaviourist perspective (as in psychological approaches) without explicit recognition of how incentive programs also effect change by articulating values (as noted in broader social science approaches). Management and governance approaches were commonly discussed as managing several sectors together (integrated management), but much less frequently discussed for early action to address emerging threats (precaution) or managing for resilience and adaptation (these are more explicit in the freshwater realm). Many studies across all foci identified particular environmental regulations, but fewer explicitly considered consistency of monitoring and enforcement although this is often crucial and implicit in scenarios (See 5.4.2.1 about incentives, 5.4.2.2 about integrated management, 5.4.2.3 about precaution, 5.4.2.4 about governing for resilience, and 5.4.2.5 about law and its enforcement).

5.4 KEY CONSTITUENTS OF PATHWAYS TO SUSTAINABILITY: ADDRESSING THE INDIRECT DRIVERS OF CHANGE

The scenario analysis in 5.2 and 5.3 demonstrated that pathways to achieve SDGs and biodiversity targets imply fundamental changes from current trends in all of the world's regions. They are in one sense extremely ambitious, while also necessary and apparently feasible. This scenario analysis also provides key insights about the pathways to realizing the full suite of goals for biodiversity and ecosystem services, but it is not a sufficient source for such insight. Our analysis revealed that some of the issues considered in the literature as central to social-ecological transitions and transformations were largely implicit or even absent in many of the target-seeking and sustainability-oriented scenarios we consulted, such as the role of formal and informal institutions, and other indirect drivers (chapter 2). Following this insight and to characterize the constituents of sustainable pathways comprehensively, the sections below interweave evidence from the scenario analysis (5.3) with evidence from diverse literatures (including those discussed in 5.2.1).

We organize this synthesis of key constituents of pathways to sustainability via eight points of leverage for social-ecological change, and five types of interventions or 'levers' of institutional change for sustainable pathways. These key points of intervention in social-ecological systems can be thought of as 'leverage points' (Abson *et al.*, 2017; Meadows, 2009), while 'levers' are management or governance interventions to effect the transformative change that achieves the collectively agreed-upon objectives for nature and its contributions to people. Note that we use the notion of 'lever' metaphorically, recognizing that global systems—as complex social-ecological systems—cannot be manipulated as neatly as can a boulder with a stick. Rather, we use 'lever'/'leverage point' to illustrate only that these levers and leverage points offer crucial opportunities to engender changes in economies and societies towards achieving shared goals.

Second, levers and leverage points are independently important: the five levers pertain more broadly than the eight leverage points, and other tools may be needed to achieve desired changes in the leverage points. The pathways we identify involve considerable flexibility in *how* to, for instance, promote positive changes in leverage points such as consumption or inequalities. Chapter 6 provides the needed account of policy options for intervention at these specific points. Our five levers, meanwhile, are intended to suggest general and systemic interventions; they are policy tools or governance approaches that are themselves key constituents of social-ecological transitions, to be considered broadly, simultaneously addressing many leverage points and social variables. There are no governance panaceas for social-ecological sustainability (Ostrom, 2007).

Change in any of these levers and leverage points may appear difficult to achieve, but we argue that many are easier to achieve in sets. Change in one aspect may enable change in others (5.4.3 details several nation-scale case studies). For example, changes in laws and policies will enable and underpin changes in management, consumption, and other aspects of behaviour. The reverse is also true: changes in individual and collective behaviours and habits can facilitate changes in attitudes, policies, and laws. Because of these bidirectional influences, there is no one way to order the levers and leverage points. Here we present the leverage points in an order that proceeds clockwise around the outside of the IPBES conceptual framework, spiralling into institutions at the end; levers are ordered from most labile to most lasting and structural (i.e., incentive programs are most easily changed, law hardest) **(Figure 5.7)**.

The analyses of leverage points and levers are organized into three sections. The first section examines each of the identified leverage points as they relate to important dimensions of global social-ecological systems (5.4.1), while the second section discusses levers of change (5.4.2). Each subsection within starts with a statement of the leverage point or lever, followed by any needed *Background*, *Evidence* and a brief discussion of *Possible points of action* (with more detail found in chapter 6). The last section provides examples illustrating leverage points and levers in action, both via national case studies and potential alternative routes that proceed from the bottom up (5.4.3).

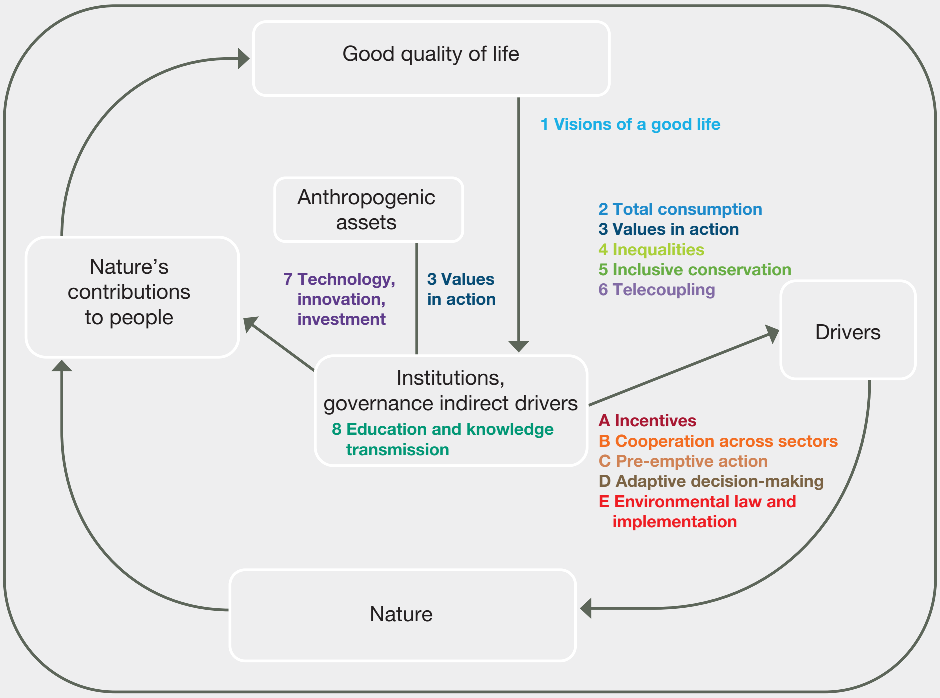

Figure 5 7 **Eight featured leverage points and five levers of transformative change toward sustainable pathways, overlaid on a simplified version of the IPBES Conceptual Framework.**

The leverage points (numbers) and levers (letters) vary in many dimensions, but each has the property that a relatively small change could effect a large change in outcomes for nature and its contributions to people. Change in one leverage point or lever can in many cases also help change others e.g., a change in visions of good quality lives (1) could greatly enable changes in consumption (2). All pertain somewhat to human formal and informal institutions, and in most cases the relationships of these institutions with other elements of the conceptual framework (in particular all five levers could be situated within the Institutions bubble, but they do pertain especially to direct drivers). Figure text for levers and leverage points differs slightly from the subsection headings, for brevity.

5.4.1 Leverage Points for Pathways to Sustainability

5.4.1.1 Visions of a good quality of life and well-being

One of the key drivers of the overexploitation of nature is the currently popular vision that a good life involves happiness associated with material consumption (5.4.1) and success based largely on income and demonstrated purchasing power. However, as communities around the world show, a good quality of life can be achieved with a significantly lower impact on natural resources and ecosystems. Alternative conceptions of a good life can be promoted without paternalism, by valuing and providing the personal, material, and social conditions for a good life with a lower material impact, and leaving to individuals the choice about their actual way of living. In this respect, the renaissance of more relational notions of well-being may be key to achieving nature-based targets. By highlighting the importance of relations to other human and non-human others for a good life we might not only contribute to decoupling consumption and well-being, but also enhance quality of life.

Background

In the academic literature, different terminologies are used to address well-being, happiness, and the good life. In general, 'happiness' refers to self-reported assessments, in which people are asked to articulate via qualitative or quantitative surveys their satisfaction with their own life. 'Quality of life' usually refers to objective indicators (such as the HDI—Human Development Index) that aggregate different data about some essential components of a dignified human life (such as life expectancy, morbidity, education & literacy, inequality). The term 'good life' is more comprehensive and includes the ancient concepts such as "eudaimonia" or "buen vivir", implying in their own way satisfaction with one's own living conditions, aspirations, and meanings, while considering collective and personal principles and virtues (see chapter 1). All these concepts (or philosophies) refer to 'agency', i.e. the ability to decide about how to live according to one's own core values (Sen, 2009). Other than preferences, which are often arbitrary and causal, core values based on deeply held beliefs and guiding principles operate as the basic points of orientation for actions and decisions. Core values can be articulated and justified to others. The concept of a 'good life' is thus linked to forms of justification and claims of justice and goes beyond immediate preferences or feelings of satisfaction.

Approaches to assessing well-being through only objective or subjective measures have generally suffered from criticism. Focusing only on resources underplays the fact that availability of resources does not ensure that they are converted into actual well-being (Nussbaum, 2003). Not only personal differences, but also environmental, institutional, and cultural conditions influence the way in which resources contribute to a good life. Focusing only on self-reported assessments gives insight into what people subjectively consider important for happiness (Layard, 2005), but, if not combined with objective indicators (Happy Planet Index; Bhutan Gross Domestic Happiness Index), it neglects the influence of external factors in determining self-assessment; it might also overlook forms of oppression (self-reported happiness can derive from ignorance of possible alternatives or entitlements, or as a coping strategy under distress). Moreover, people can decide to act according to other motives (altruism, care, etc.) against their personal happiness or advantage, thus following core values in the sense described above.

It is contested how material wealth and growth per capita correlate with (subjective or objective) well-being. While some studies show that, after a certain threshold additional wealth yields diminished happiness returns or decouple from quality of life (Binswanger, 2006; Easterlin *et al.*, 2010; Helliwell *et al.*, 2012; Jackson, 2009; Layard, 2005; Max-Neef, 1995), other recent studies contest these findings (Ortiz-Ospina & Roser, 2017; Veenhoven & Vergunst, 2014). Relative to average or aggregate income, inequality seems to have a larger negative impact on subjective and objective well-being (Oishi & Kesebir, 2015; Wilkinson & Pickett, 2010). It is widely agreed that there is no automatic or obvious correlation between wealth and well-being, but that it depends strongly on institutional, social, and cultural settings that guarantee essential conditions to achieve a good life.

Given the great diversity of conceptions of a good life and well-being, it is important to focus on the *conditions* for leading a good life rather than on the ways in which people actually (choose to) live their lives (Nussbaum, 2000, 2003; Sen, 1999). Such a focus on conditions avoids problems of paternalistic intervention (influencing or forcing people into choosing a specific conception of a good life). A plurality of options for actualization is available once the basic conditions for a good life are guaranteed. Attention can then focus on what process, group, or institution has the legitimate authority to decide what people have reason to value (Deneulin & Shahani, 2009), and to the substantial conditions for participation, including domination structures, actual access conditions, and effective 'power' to be heard and make a difference. Institutions play a key role in framing enabling conditions for a good life. Experiencing life in an environment devoid of dangerous impacts such as those associated with global warming, can be considered a 'metacondition' ('ecological functioning capability'; Holland, 2008; Page, 2007).

Conditions can be *subjective* (preferences), *objective* (material or institutional), and *intersubjective* (social or cultural) (Muraca, 2012). For example, affording shoes can be considered as a subjective condition for happiness (if one loves shoes, collects them, etc.), as an objective condition for being, say, healthy (especially in cold countries), and/or as an intersubjective condition for leading a good life in the face of others in a society, in which wearing shoes is considered a symbol for decency and reliability (Sen, 1987).

When addressing policy interventions about well-being, intersubjective conditions are often neglected, although they play a crucial role especially for change in consumption patterns. Overconsumption is often not only a result of subjective preferences, but also of infrastructural or cultural conditions. For example, if everyone else drives a sports utility vehicle (SUV), driving a small car on the highway is not only a matter of social status but also of personal safety. Having a smartphone up to date is increasingly a necessity for work, but also for access to health services or for social interactions. Such social conditions depend on cultural patterns that influence and are influenced by institutional framing.

Evidence

The orientation towards ways of living based on high material and energy flows is supported by shared values that promote happiness as based on material consumption and success demonstrated mainly via purchasing power and economic status. This model supports what has been termed an 'imperial mode of living' that arguably stabilizes the economies of developed nations while offering a hegemonic orientation to developing countries (Brand & Wissen, 2012).

Since concepts of the good life are influenced by institutional settings and social expectations, social and institutional change can foster alternative conceptions of a good life and guarantee prosperity (Jackson, 2009) with lower material impacts on resources and ecosystems (Røpke, 1999) if combined with the promotion of the fundamental conditions for guaranteeing flourishing (Jackson, 2009; Nussbaum, 2000, 2003). As evidence suggests, competition, inequality, and acceleration of the pace of life—essential components of the idea of a good life based on material consumption—in the long run lead to dissatisfaction (Binswanger, 2006; Easterlin *et al.*, 2010).

A promising path is offered by a widespread renaissance of more relational notions of well-being embodied in various initiatives, social movements, and social groups also in developed countries (see for example the Convivialist Manifesto: http://dialoguesenhumanite.org/sites/dialoguesenhumanite.org/files/meetuppage/103/convivialist-manifesto.pdf; the European Degrowth movement (D'Alisa *et al.*, 2014); or the Transition Town movement (Hopkins, 2008). In Latin America, the promotion of the old concept of "Buen Vivir" also embodies collective deliberations on the conditions of a good life for all, including the rights of nature and ecosystems to flourish. Increasing evidence also supports the conclusion that significant relationships with nonhuman nature are constitutive of a good life for many people both in developed and developing countries (Arias-Arévalo *et al.*, 2018; Chan *et al.*, 2016; Kohler *et al.*, 2018; Muraca, 2016). The use of concepts such as 'relational values' help articulate a more adequate language for why people are willing to invest time and attention to the care of ecosystems (Chan *et al.*, 2016; Muraca, 2016; also see chapter 1).

The notion of a good life that most Indigenous Peoples share is deeply relational: the relation to the land with all its interconnected human and nonhuman inhabitants constitutes their collective self-understanding as community. Livelihoods sovereignty is an essential condition to keep this bond. In Ecuador, the rights of Mother Earth (Pachamama) to preserve its condition of regeneration (a different language for biodiversity and ecosystem services) are considered as inseparable from the conditions for a good life of the people and are protected by the Constitution. The Bolivian Constitution includes the consideration of diversity not only ecologically, but also culturally, affirming the rights of the different and diverse indigenous communities in the conception of a plurinational State. These contributions of nature to notions of a good life may be under threat as access to nature—or key components of nature—are lost (Chan & Satterfield, 2016; Garibaldi & Turner, 2004; Kohler *et al.*, 2018; Louv, 2008; Miller, 2005; Nabhan & St Antoine, 1993).

Possible points of action

Governments and other institutions are responsible for enabling subjective, objective, and intersubjective conditions for a good life. Successful policies would generally target the different drivers that affect the desirability and burden of alternative ways of being: socioeconomic (such as competition-driven investment in innovations and the need for new market opportunities), structural (dominant understandings that equate economic growth with well-being), and socio-psychological and cultural (including the social relations in which humans are embedded) (Røpke, 1999).

Promoting alternative conceptions of a good life does not require paternalistic interventions: if the material, social, and personal conditions for a good life are sustained in ways that do not require a high material and energy flow, individuals have the freedom to choose alternative modes of living without significant impairing their quality of life. In this case, sufficiency would not only be an individual choice of voluntary simplicity, but also the legitimate entitlement to a sufficient lifestyle, i.e., the right to have less, to have a slower pace of life, to escape the escalating competition for success and enhancement ('hedonic treadmill'; Binswanger, 2006), without suffering a significant lack in the conditions for a meaningful and dignified life (Winterfeld, 2007). For example, if access to essential services (such as communicating with one's physician or buying a bus ticket) requires specific up-to-date technology, choosing not to use them heavily impacts access to health and mobility. Institutional framing can make the choice of a sufficient and low-impact lifestyle achievable for a large majority of the population, by eliminating burdens or negative incentives.

Improving affordable, spatially inclusive and comprehensive public transport infrastructure would expand fundamental entitlements to mobility, enabling people to embody more collective notions of a good life without substantial compromise to security, comfort and efficiency.

Regulation of planned obsolescence for technological products would shift innovation towards ecological design and long-lasting, modular products, thus increasing the freedom of choice of consumers while improving the social and environmental conditions under which electronic devices are produced. It would also in the long run affect the cultural understanding of innovation and originality while significantly reducing environmental impacts (e.g., through rare earths mining).

Expectations of increasing speed in social interactions often correlate with increasing impact on nature due to associated infrastructural needs. Policies and programs that counteract acceleration tendencies and promote spaces for solidarity, care, creativity, and democratic participation might enable the achievement of essential features of a good life and expand freedoms. Technological innovation can significantly contribute to reframing the conditions of acceptability of social behaviours as well (e.g., the "do not disturb while driving" feature on recent smartphones might reduce the expectation of immediate response to messages).

Such interventions would foster a shift—in the long run—from the role of consumers to that of users (Lebel & Lorek, 2008) without significantly impairing the capabilities of people to achieve valuable doings and beings. Supporting alternative modes of production based on peer-to-peer processes would increase local resilience, make technologies accessible and decentralized, and promote the autonomy and self-determination of local communities (Kostakis & Bauwens, 2014).

Ultimately, a fundamental condition for a good life is the possibility of deliberation and negotiation within a society. Participatory parity (Fraser, 2007) is key. This entails different social groups being able to speak in their own terms and language about their understanding of a good life and enabled to participate in the framing of its conditions (Fraser, 2007).

5.4.1.2 Aggregate consumption (a function of population, per capita consumption and waste)

Beyond improved efficiencies and enhanced production, all pathways to reducing biodiversity loss entail reducing or reversing the growth of aggregate consumption, as a function of population size and per capita consumption and waste. Per capita consumption tends to rise as income rises, putting further pressure on biodiversity. Upward trends in population growth have and will lead to further biodiversity loss and increasing numbers of threatened species. The need for transformative changes in consumption patterns is particularly pertinent for wealthier nations and people.

Background

Across 114 nations, the number of threatened species in the average nation is expected to increase by 14% by 2050 (McKee *et al.*, 2004); and increased efficiency in food production is unlikely to compensate sufficiently for the negative impact of human population growth and increasing per capita consumption on biodiversity (Crist *et al.*, 2017). Expected changes in population and income between 2010 and 2050 suggest that the environmental effects of the food system, as one example, could increase by 50–90% without substantial technological changes and dedicated mitigation (Springmann *et al.*, 2018a). Globally, decreases in consumption are thus critical, recognizing that there are significant inequalities within and between countries in consumption related to food, energy, water, and other natural resources (O'Brien & Leichenko, 2010).

Aggregate consumption is a function of population size *and* per capita consumption. An example of these effects at a fine scale is that households with fewer members tend to have higher per capita consumption, with consequences for biodiversity, especially in biodiversity hotspots (Liu *et al.*, 2003). Cities are more efficient resource-users per capita than sparsely populated areas due to economies of scale, in particular with infrastructure (EEA, 2015). On the other hand, urbanization has also been found to increase consumption at the household scale. Specifically, the ecological footprints (an index of major consumption categories at the household level; see chapters 2 and 3) of nineteen coastal cities across the Mediterranean reveals that per capita footprints are larger on average than parallel rural populations. The main drivers were found to be food consumption, transportation and consumption of manufactured goods (Baabou *et al.*, 2017). In general, the co-benefits of urban systems as both source and solution of environmental effects are not well studied.

Evidence

Aggregate consumption (the product of population size and per capita consumption and waste) is undisputably a key driver of environmental degradation (Dietz *et al.*, 2007; Ehrlich & Pringle, 2008; Rosa *et al.*, 2004). As one prime example, food consumption drives the agricultural sector (which covers 38% of Earth's surface), and is as a primary source of environmental degradation and GHG emissions (both drivers of biodiversity loss). Seventy-five per cent of that agricultural land is used for livestock production (Foley *et al.*, 2011). In particular, demand for animal source foods has more than tripled over the past 50 years due to population growth and dietary change (Delgado, 2003; Thornton, 2010). Livestock production (grazing and feedstock) is the single largest driver of habitat loss, a pattern increasing in developing tropical countries where the majority of biological diversity resides. The projected land base required by 2050 to support livestock production in several megadiverse countries exceeds 30–50% of their current agricultural areas (Machovina *et al.*, 2015). Some reduction in biodiversity loss can be offset through technological gains such as yield gains in agriculture due to intensification (Wirsenius *et al.*, 2010), but these do not yet keep pace with simultaneous growth in population and income (West *et al.*, 2014).

Changes in consumption patterns are among the most prominent elements in storylines used in scenarios that lead to achieving SDGs, including all three elements (population size, per capita consumption, and waste). The core global studies (Roads to Rio+20, Pathways to the 1.5ºC target, and Bending the Curve—5.3.1.2) all assumed relatively low stabilized global population sizes and various scenarios of reduced overconsumption and waste. More specifically, Stehfest *et al.* (2009) showed that four scenarios of dietary variants, all involving reduced meat consumption yielded diminished land-use change (and associated, non-modelled, benefits for BES) and reduced emissions and energy demand. Meanwhile, energy scenarios suggest that focusing on the energy use of sectors, not people, would lead to substantial reduction in energy demand (see McCollum *et al.*, 2012's energy efficient pathway).

These patterns in scenarios contain some important complexities but lack others. One key missing nuance in large-scale scenarios is the minimal representation of rebound effects (Jevons paradox), by which consumption often tends to increase in response to gains in efficiency in production or resource intensity, erasing some or all of the gains (e.g., LED lighting may be more efficient but enable much more lighting in total; more abundant energy may encourage greater consumption) (Alcott, 2005). Accounting for these rebound effects would make the case even clearer that ***increased production and efficiency are not sufficient, without also addressing consumption itself***. In terms of food consumption, modelled patterns often somewhat underrepresent variation within agricultural systems, and the important role dairy and foods of animal original play in childhood, maternal (during pregnancy) and elderly nutrition (FAO, 2016)(). For instance, few scenarios account for feedbacks between changing availability of protein affects local hunting or fishing (Brashares *et al.*, 2004), where wild-based and so small-scale economies, such as bushmeat provisioning, have also been identified as an important driver of biodiversity loss (Fa *et al.*, 2005; Nasi *et al.*, 2008). Terrestrial wildlife, especially ungulates, are a primary source of meat for millions globally. Wild meats are however an important source of childhood nutrition, without which an estimated 29% increase in children suffering from anemia would occur, leading to health, cognitive and physical deficits in poor households (Golden *et al.*, 2011). Virtually all models do include some level of meat and fish derived proteins. Furthermore, all models related to the role of dietary changes recognize that dietary changes, such as lowering animal protein consumption do not apply to undernourished and vulnerable populations. The general point is that lowering consumption of animal protein is important; and that variation aside, even the lowest impact of animal protein production typically exceed the impact of plant-based options (Clark & Tilman, 2017; Poore & Nemecek, 2018).

Waste is equally key. A large amount of food, including animal products, is wasted worldwide, e.g., roughly 30% in the U.S. when accounting for production through household waste (Nellemann, 2009). Wasting 1 kg of feedlot-raised boneless beef is estimated to have ~24 times the effect on available calories as wasting 1 kg of wheat (~98,000 kcal versus ~4000 kcal) due to the inefficiencies of caloric and protein conversion from plant to animal biomass (West *et al.*, 2014). Waste varies greatly between countries: food loss in India for vegetables and pork is <3 kcal per person day–1, versus ~290 kcal per person day–1 for beef in the United States. Approximately 7 to 8 times more land is required to support this waste in the United States than in India (Machovina *et al.*, 2015). Overall, because waste in the production cycle is so variable, even for the same food types and classes, producer-level monitoring and mitigation will be key to achieving more sustainable pathways (Poore & Nemecek, 2018).

Overproduction (when not discarded to prop up prices) and associated marketing can also drive consumption: if subsidies or other forces yield an oversupply of a commodity or good, this will lower prices, and consumption of those goods and their embodied resources will tend to rise. Producers can boost these effects strongly through advertising, which can yield self-reinforcing dynamics in consumer culture (Berger, 2015; Isenberg, 2017; Philibert, 1989).

Possible points of action

It is estimated that countering these driving forces would require incentives for increases in the efficiency of resource use of about 2% per year (Dietz *et al.*, 2007), and no single measure or action will be sufficient. Intensification will offset some effects of consumption in the agricultural sector, but much gain would accrue via reduction in meat consumption through demand reduction and dietary shifts (Foley *et al.*, 2011). As with all efficiencies, some rebound effects are to be expected and addressed (e.g., increased demand that follows initial gain through efficiency) (Alcott *et al.*, 2012).

An estimated 1.3 to 3.6 billion fewer people could be fed if diets shifted to lessen reliance on animal products, particularly resource-demanding ones (while maintaining the relative contribution of grazing systems) (Davis & D'Odorico, 2015). Some analyses suggest that targeting Western high-income and middle-income countries would yield the largest potential gain and focus for the environmental (and health) benefits of dietary changes at a per capita level (Springmann *et al.*, 2014). Improvements in consumption patterns can likely be achieved by reducing subsidies for animal-based products, increasing those for plant-based foods, and replacing ecologically inefficient ruminants (e.g., cattle, goats, sheep) (Machovina *et al.*, 2015). Research and development of plant-based meat substitutes is also a growing phenomena and potential solution (Elzerman *et al.*, 2013; see also Poore & Nemecek, 2018; Springmann *et al.*, 2014, 2018b).

Significant targeting of waste is also an important policy target; well tested approaches include regulations for Extended Producer Responsibility whereby producers manage the waste generated by their products (OECD, 2016).

Given the central role of advertising and marketing in boosting production, policies might seek to rein in the reach of advertising, particularly to children and for resource-intensive products. Lastly, broader changes in consumption could be triggered by promoting alternative models of economic growth (e.g., as proposed by the World Business Council for Sustainable Development, WBCSD, 2010), which may also offer higher likelihood of achieving SDGs 2, 6, 15.

5.4.1.3 Latent values of responsibility and social norms for sustainability

Sustainable trajectories are greatly enabled by context-specific policies and social initiatives that foster social norms and facilitate sustainable behaviours. An important step toward this goal would be to unleash latent capabilities and relational values of responsibility (including virtues and principles; 5.4.1.1). Such values may often be strongly held in relevant populations, but not manifest in large-scale action due to a lack of enabling conditions, including infrastructure and institutional arrangements. Because communities, the values they hold, and barriers to enacting values are all diverse and multifaceted, social norm-shifts and widespread action are most likely to stem from locally tailored programs, policies and investments.

Evidence

There is strong evidence that many populations already express values consistent with sustainability, such as pro-environmental values (e.g., Dunlap & York, 2008) and relational values (Klain *et al.*, 2017). These values manifest differently in different places (Chan *et al.*, 2016). For example, Haidt & Graham (2007) document a striking difference in moral foundations between progressive and conservative voters in the USA, and the World Values Survey reveals two major axes of difference (traditional vs. secular-relational values and survival vs. self-expression values) (World Values Survey, 2016). In both of these frameworks, values on either end of these spectra could support sustainability.

Ample evidence supports that the expression of such values is currently impeded by insufficient infrastructure and social structures (Shove, 2010). This 'social practice' strand of research demonstrates the need for explanations of collective action (e.g., issues involving greenhouse gas emissions) to go beyond the aggregate of individual people operating independently. This research suggests that the focus on individual attitudes, behaviours, and personal choice needs to be expanded to include systemic considerations, such as the role that governments play in "structuring options and possibilities" (Shove, 2010). As one important possibility, sometimes norms can be promoted in new contexts by foregrounding existing widely held norms and values, and their applicability to the issue at hand via a process called 'normative reframing' (Raymond *et al.*, 2013). Thus, notions of justice or fairness can be applied in new environmental contexts, either through normative reframing or even the creation of new norms in 'normative innovation' (Raymond *et al.*, 2013).

Extensive work on barriers to pro-environmental behaviour, which originates from an individual-focused paradigm, also often discusses two main realms of barriers: personal and collective. This work provides evidence that individual-level factors (e.g., disposition) play a role in behaviour, and it also confirms the importance of factors external to the individual (Darnton & Horne, 2013; Kollmuss & Agyeman, 2002). In short, though individual motivation is important, the problem is sometimes or often not that individuals lack motivation for action (e.g., on climate change), but rather that current infrastructure, habits, and norms are outdated and insufficient to express values already present. An example from the United States relates to personal transportation, many people report wanting a lower carbon alternative to personal vehicle travel, but their communities are designed in such a way that make other options prohibitively inconvenient and/or unappealing (Biggar & Ardoin, 2017b, 2017a; Shove & Walker, 2010).

Related to the point above, but stemming from a parallel literature, extensive behavioural economics and psychological research suggests that human decisions are heavily impacted by context and structures. There is strong evidence from a range of studies and a larger body of social sciences literature that replacement or evolution of infrastructure and social structures could nudge change in individual behaviour and also contribute to the formation of pro-sustainability habits and norms (Pallak *et al.*, 1980; Thaler & Sunstein, 2008). A fundamental idea underlying this philosophy, which has been called "liberal paternalism" because it allows free choice (liberal) but guides people (paternalistic), is that people often want to act differently than they do, and would often appreciate a "nudge" to help them act in accordance with their deeper values. One specific example would be that people wanting to purchase sustainable seafood have benefited from a green-yellow-red signaling system, especially when those signals are displayed beside the products in stores and restaurants. A more general example would be that people wanting to donate more to charity generally give more with automatic payment plans.

Additional evidence suggests that despite the responsiveness of human behaviour to existing contexts, moral belief and conviction already do transcend purely selfish action and/or more mechanical responses (e.g., of the type described by moral psychology or behavioural economics) (Damon & Colby, 2015). Learning can help people develop these responses based on morals and conviction, especially when that learning employs dialogue, reflection, reasoned argumentation, and deliberation (all of which practices are increasingly recommended by education scholars; see 5.4.1.8). A cornerstone of much moral philosophy is the idea that people can engage with complex situations and, through conscious deliberation and moral judgement, change behaviours and lifestyles. Acknowledging the aforementioned substantial impact of sometimes minor situational and contextual variables, it is helpful to also consider research into human moral choice, and how morality and moral decisions come about. Much research in this realm highlights the importance of intentional effort, deliberative discussion and thought (including in education), not as an alternative to 'nudge' approaches but as a complement (John *et al.*, 2009; Reed *et al.*, 2010).

Fifth, the burgeoning science of norms offers important insight into how to change behaviour. The science of norms considers the interplay of proximate contextual factors (e.g., what people around us are doing) and more deeply rooted social, collective understandings of "how things should be." Norm-based interventions are some of the most prevalent and effective means of changing behaviour (Miller & Prentice, 2016). As one example, household use of electricity decreases following messages about neighbors who use less electricity (the addition of a message conveying social approval/disapproval further strengthens the change; Schultz *et al.*, 2007). Norms interventions, particularly related to environmental issues, are less common in developing countries; an example from the health field is that decreases in female genital mutilation followed interventions that attended to social norms along with other aspects of local context (Cislaghi & Heise, 2018). Research on the dynamics of norms (i.e., how norms change) focuses on the need to change expectations, both about what others will do and what others think people should do (Wegs *et al.*, 2016). Legislation can affect these changes under specific conditions (e.g., when policies are not too far from aligning with existing social norms) (Bicchieri & Mercier, 2014). For most cases, however, interpersonal interaction is central to changing norms. Discussion can encourage prosocial behaviour by signalling and emphasizing desirable behaviours and norms (Balliet, 2009; Sally, 1995). Discussions also help people understand why others feel as they do and allow people to grapple with disagreement. In some situations, for instance those in which people need to be convinced, argumentation may be required (Bicchieri & Mercier, 2014). Work from a variety of fields confirms the importance of interpersonal interaction and discussion; one study, for instance, found time spent with neighbors to be strongly correlated to "environmental lifestyle" and "willingness to sacrifice", emphasizing the importance of non-kin social relationships and interactions (Macias & Williams, 2014).

For IPLCs, values of all kinds (e.g., instrumental, intrinsic, relational) are deeply intertwined with cultural and environmental contexts, and value systems are often represented in and reinforced by language. The loss of language may be associated with value deterioration or change. Many (if not all) languages codify values related to the ability to coexist with surrounding environments for hundreds or thousands of years (Davis, 2009; Maffi, 2001). These sustainability-related values may be particularly common in Indigenous and other long-standing local communities, with their strong traditional beliefs, laws, customs, culture, and affections towards nature (e.g., sacred trees, sacred animals, totems) (e.g., McGregor, 1996; Turner, 2005). As such, the loss of languages is potentially a major problem for value diversity and authenticity. In many regions, community values that support sustainable trajectories using indigenous knowledge are at risk of extinction, which results in the loss of biodiversity (Unasho, 2013). Loh and Harmon (2014) note that one in four of the world's 7000 languages are at current threat of extinction, confirming a simultaneous decline in linguistic diversity and biodiversity – approximately 30% since 1970. Extinction statistics tell the story: 21% of all mammals, 13% of birds, 15% of reptiles, 30% of amphibians and 400 languages have gone extinct (Loh & Harmon, 2014). In this sense, the value of the knowledge-practice-belief complex of Indigenous Peoples relating to conservation of biodiversity are central to the sustainable management of ecosystems and biodiversity.

Possible points of action

A particular challenge faces people participating in global supply chains (e.g., through their purchasing of goods and services), because although there might be broad and strong agreement with the notion that we humans have a responsibility to account for our impacts on the environment (Klain *et al.*, 2017), there are a dearth of options for people to do so easily, enjoyably, and affordably (Chan *et al.*, 2017b). That is, the primary option available to consumers is the purchase of certified products (e.g., Marine Stewardship Council seafood, forest-stewardship council wood products, organic food), but these are inevitably costly, limited, and complex (few consumers can keep track of and come to trust more than a few of the plethora of competing labels). Because the costliness stems partly from inefficiencies in these niche supply chains, there is potential to enable widespread action in accordance with values of environmental responsibility via credible non-tradeable offsets that enable organizations and individuals to mitigate their impacts on nature (Chan *et al.*, 2017a). A legitimate and trusted system of such offsets does not yet exist, but there are important developments and novel efforts (e.g., the Natural Capital Project's Offset Portfolio Analyzer & Locator, Forest Trends' Business & Biodiversity Offsets Programme, CoSphere).

Offsets have a potentially important role to play because they could enable people and organizations to enact values of environmental responsibility that are currently suppressed by disabling conditions, but which could potentially yield new social norms. However, to achieve that, it will be crucial that offsets avoid the problems and associated negative reputation that has plagued carbon offsetting, such that offsets convey the real and socially legitimate mitigation of diverse impacts on nature and its contributions to people (Chan *et al.*, 2017a).

5.4.1.4 Inequalities

Inequality often reflects excessive use of resources or power by one or more sectors of society at the expense of others. As societies develop and aim to 'catch up' in economic growth, inequality often emerges through control and appropriation of unequal shares of finite resources with implications for both creating unjust social conditions and loss of nature and its contributions. Therefore, addressing societal inequities is not only important for its own sake and for moral reasons, but as leverage to facilitate achievement of biodiversity goals.

Background

The world is currently experiencing increasing levels of inequality in many sectors of society, including between, within countries and across countries (Stiglitz, 2013). Although assessments of inequality often focus on income, there are many dimensions of societal inequalities such as distributive, recognition, procedural and contextual inequities (Leach *et al.*, 2018). Distributive equity refers to the distribution of costs and benefits, and questions of who gains and who loses. This is very applicable for example to the climate discussion where questions are raised about who bears the responsibility for or burdens of climate impacts (Collins *et al.*, 2016; Dennig *et al.*, 2015). This may also include discussion about unequal access to health across and within countries (Costello & White, 2001; Joshi *et al.*, 2008) or inequality in access to energy (Lawrence *et al.*, 2013; Pachauri *et al.*, 2013) and inequalities in income distribution (Alvaredo *et al.*, 2018; Piketty & Saez, 2014; Ravallion, 2014). Procedural equity refers to access and participation in decision-making processes and applies to discussion about gender inequality and representation in governance structures, education, and other spheres of society (McKinney & Fulkerson, 2015). Recognition equity refers to accounting for stakeholders' knowledge, norms and values, and this is the main driving force behind IPBES and other organisations' calls for including indigenous and local knowledges, expanding the values base and opening up to multiple forms of evidence (Díaz *et al.*, 2015; Nagendra, 2018; Pascual *et al.*, 2017a; Tengö *et al.*, 2017). Finally, contextual equity refers to deep rooted social conditions, such as gender, social structure, discrimination and historical legacies that help to explain why inequality is perpetuated and reproduced over time (Martin *et al.*, 2016; McDermott *et al.*, 2013). All these different dimensions of inequities and inequalities can apply variously to gender equity, equity between specific groups, or between vulnerable groups and between different segments of society (Bock, 2015; Daw *et al.*, 2015; Keane *et al.*, 2016; Terry, 2009).

Evidence

Global inequalities, between and within countries, include inequities in income and wealth, inequities in access to resources and other benefits, as well as inequities in who bears the brunt of global change.

Globally, income inequality is increasing while biodiversity loss continues apace (Butchart *et al.*, 2010; Dabla-Norris *et al.*, 2015). Although the mechanisms of how income inequality affects biodiversity loss are not yet articulated comprehensively, there is some indication that income inequality is positively correlated with biodiversity loss. Inequality has been associated with an increasing number of social and environmental problems (Islam, 2015; Jorgenson *et al.*, 2017; Wilkinson & Pickett, 2010). Several studies suggest some initial hypotheses for the observed negative coarse-scale correlations between biodiversity and inequality (Holland *et al.*, 2009; Mikkelson *et al.*, 2007; Mikkelson, 2013). Here income inequality, measured using the Gini index, is correlated positively with threatened species, suggesting that inequality may exacerbate biodiversity loss. It also appears that a psychological acceptance of inequality (as measured by the social domination orientation) is negatively correlated with a variety of environmental actions and behaviours, and that this negative relationship is stronger in nations characterized by societal inequality (Milfont *et al.*, 2017).

More broadly however, inequality is seen as resulting from broader structural issues. In this way, unequal access to incomes, resources, consumption and other forms of inequality are symptoms of larger structural configurations related to power asymmetries and political influence (Cushing *et al.*, 2015; Pieterse, 2002). Some of explanations of this assertion include the existence of phenomenon such as 'ecologically unequal exchange', which is a structural mechanism allowing for more developed countries to partially externalize their consumption-based environmental impacts to lesser developed countries (see chapter 2.1; Jorgenson *et al.*, 2009). While there are some nuances to this suggestion (Moran *et al.*, 2013), there is evidence showing unequal consumption patterns between developed and developing countries (Wilting *et al.*, 2017), and 'trade of biodiversity' from developing countries to developed countries (Lenzen *et al.*, 2012). For example, there is evidence suggesting inequalities in access to health (Costello & White, 2001; Joshi *et al.*, 2008), energy access (Lawrence *et al.*, 2013; Pachauri *et al.*, 2013), climate change and other environmental burdens and responsibility (Collins *et al.*, 2016; Dennig *et al.*, 2015), income distribution (Alvaredo *et al.*, 2018; Piketty & Saez, 2014; Ravallion, 2014), between countries, individuals, genders and other socially differentiable segments of society (Aguiar & Bils, 2015; Bebbington, 2013; Chaudhary *et al.*, 2018; Lau *et al.*, 2018; Piketty & Saez, 2014).

Possible points of action

There are increasing numbers of suggestions and solutions for addressing inequality in society. For example, the concept of 'common but differentiated responsibility' has taken root in multinational agreements, is now a principle within the United Nations Framework Convention on Climate Change (UNFCCC). It acknowledges the different capabilities and differing responsibilities of individual countries in addressing climate change (Rajamani, 2000; Stone, 2004). Given different countries' historically different responsibilities and benefits in use of and access to resources, this principle could be applied more broadly to other spheres of biodiversity management.

Within nations, there are other solutions to inequality such as United Nations Development Programme's Inclusive Growth (UNDP, 2017). Others still advocate for universal provision of services including universal health care, universal education, basic social services, and regressive taxation. One of these universal provisions that is gaining traction is universal basic income (Lowrey, 2018).

5.4.1.5 Human rights, conservation and Indigenous Peoples

Sustainable trajectories that achieve biodiversity and Sustainable Development Goals need to maintain or enhance ecosystem services on which livelihoods depend as concerns Indigenous Peoples and land-based (and often poor) people living in or adjacent to all classes of protected areas. Achieving large-scale engagement of Indigenous Peoples and Local Communities (IPLCs) in protected areas governance entails (a) recognition of and compensation for historical wrongs and transgressions of rights in conservation contexts; (b) IPLC-led planning, decision-making and consent (which is significant and robust); and (c) connection of local efforts with larger connected landscapes/seascapes to enable the continued benign use of ecosystem services in broader landscapes and seascapes. Human rights are linked to but not inclusive of the rights of nature across these considerations.

Evidence

Some conservation efforts have led to Indigenous Peoples and Local Communities being displaced from traditional territories and deprived of access to resources essential to their livelihood (Agrawal & Redford, 2009; West & Brockington, 2006; see also chapters 3 and 6). This was true across many colonial administrations wherein reserves were often created as hunting reserves or settler communities (Griffiths & Robin, 1997; Neumann, 1998). These reserves impinged upon forest and land-dependent communities (Duffy *et al.*, 2016). There are also reports of similar patterns of restrictions and conflicts with contemporary pastoralists (Holmern *et al.*, 2007) and swidden agriculturalists (Harper, 2002). As conservation efforts have escalated in the contemporary period, this pattern has continued, with some exceptions (Davies *et al.*, 2013). International organizations in the last two decades have come to recognize that the involvement of local people is an essential prerequisite of any attempt to achieve better conservation and natural resource management (Kakabadse, 1993; McNeely, 1995). However, there have been ongoing reports of violent and militarized conservation actions including shoot-to-kill orders issued for poachers (Lunstrum, 2014). Recent examples come from the USA, Cambodia and southern African countries (Ramutsindela, 2016), including cases where relocation has failed and violence has escalated as a partial consequence (Hübschle, 2016).

In many countries, both in Global North and South, the processes of allocating land rights are still a work in progress. People with legitimate and historical rights to territorial use and jurisdiction have often had difficulty gaining recognition of these rights in processes of land allocation. Misidentifying people as stakeholders rather than rights-holders has often enabled human rights abuses by lessening the obligations of duty bearers (those responsible to protect and enable viable conditions such that human rights are ensured) (Alcorn & Royo, 2007). Failure to recognize the presence and role of historical wrongs has often deepened or exacerbated tensions about or the creation of just forms of conservation (Chan & Satterfield, 2013). This has included histories of displacement often linked to 'fortress conservation' (Büscher, 2016), forced relocation and loss of livelihoods (Brockington & Igoe, 2006), colonial legacies, transgression of treaty rights, and failed restitution for historical losses (Colchester, 2004). The designation of protected areas without meaningful involvement of those most affected (Hockings *et al.*, 2006) has been widespread, so much so that some populations are not aware that they are living within a designated protected area and that conditions of use have thus changed (Sundberg, 2006).

Pressure from national and international organizations related to human rights and to conservation has placed pressure on policymakers in countries with rich biodiversity, sometimes with undesirable effects. Even attempts to achieve conservation through community-based management have not always fully addressed the fundamental rights of local people, even in better designed systems such as those known as community-based conservation (Berkes, 2004; Campbell & Vainio-Mattila, 2003). Cernea and Soltau (2006) have documented cases where conservation has deepened poverty and food insecurity as a result of restrictions imposed on resource use, most acutely in cases of forced relocation or involuntary resettlements. Sachs *et al.* (2009) have documented cases where a disproportionate conservation burden has been placed on already poor and marginal communities thereby increasing transitions into more severe forms of poverty.

The loss or degradation of social status has also accompanied conservation activities, often due to the relocation of peoples to hostile host communities (Martin, 2003) or the stigmatizion of some peoples because their land-use practices are deemed destructive by conservation agents (Bocarejo & Ojeda, 2016). Compensation for losses directly attributable to conservation (e.g., due to loss of lands, or loss of resources or income as the result of human-wildlife conflicts) have often been insufficient (Cernea & Schmidt-Soltau, 2006) or have failed to recognize losses most meaningful to impacted communities (Witter & Satterfield, 2014). Communities have often waited far too long in far too compromising circumstances for promised relocation packages when being moved to improve the status of parks and protected areas (Hübschle, 2016). Lastly, when conservation efforts have been poorly executed due to problems of governance, corruption, or in areas with histories of war and armed conflict, violent and militarized conservation has often ensued and harmed human and nonhuman communities (Smith *et al.*, 2015).

Given the vast lands over which IPLCs exercise traditional rights, recognizing land rights and partnering with Indigenous Peoples could greatly benefit conservation efforts (Garnett *et al.*, 2018). According to Garnett et al. (2018), Indigenous Peoples either traditionally own, manage, use or occupy at least a quarter of the global land area, constituting approximately 40% of land that is currently protected or ecologically intact. IPLCs frequently have a rich set of relational values regarding nature and their interactions with it, and some of these are consistent with conservation, although often not as it has been practiced historically (through exclusion) (Chan *et al.*, 2016; Pascual *et al.*, 2017a). Involving IPLCs justly and appropriately in conservation could help them manage other pressures, such as resource extraction, in a way that meets both local and global needs.

Possible points of action

Recent innovation among conservation organizations has seen investments in engaging local communities in exploring future scenarios to achieve conservation and development, thus involving communities at an early stage of conservation and sustainable development programs (Boedhihartono, 2017; Clarke, 1990; Curran *et al.*, 2009; chapter 6).

Needs remain, however, for measures to directly and indirectly address enduring negative consequences of conservation for local and Indigenous Peoples. Improved forms of community-based conservation might ensure that the rights of nature do not supersede human rights (Hockings *et al.*, 2006). For instance, conservancies established in southern Africa have enabled local decision-making to be sustained across decades (Boudreaux & Nelson, 2011; Tallis *et al.*, 2008). Many countries are beginning to return land and forests to local communities and indigenous groups. Notable successes have been achieved in the last decade, and wider adoption of such programs for forests and biodiversity conservation could address the issues raised here (Adams, 2001; Boedhihartono, 2017; Sayer *et al.*, 2017).

Adaptive management (5.4.2.4) is viable when people are well integrated into the social-ecological system being conserved, and distribution of economic and social benefits contribute to improve the lives of IPLCs (Berkes, 2004; Infield & Namara, 2001). There are examples of successful action drawing on traditional ecological knowledge and practice, which have been combined with western concepts of conservation to produce multi-disciplinary management outcomes (Gadgil *et al.*, 2000; Huntington, 2000).

Enabling local definitions and targets for nature's contributions to people is also key, especially those that go beyond market measures and enhance well-being (Sandifer *et al.*, 2015). Working with locally-defined compensation and resettlement planning can help improve or restore livelihoods and development opportunities (Bennett *et al.*, 2017; Vanclay, 2017). Compensation for crop losses can also improve support for conservation initiatives and is being widely used, though challenges remain (Karanth & Kudalkar, 2017; Nyhus *et al.*, 2005).

In the rare instances where relocation appears necessary, fairness might dictate the suspension of processes if they cannot be realized well and fairly in an appropriate time frame (Hübschle, 2016). Strong stances against militarized and armed conservation will help restore deeply eroded people-park relations and 'de-criminalize' livelihoods (Duffy *et al.*, 2015).

Schemes such as payments for ecosystem services (PES) are most likely to succeed in conditions where livelihoods are already relatively secure, and payments are supplemental and not a replacement for income or food security (Pascual *et al.*, 2014).

The social complexities of landscapes can be integrated when designing compensation schemes for conservation at community levels (Wunder *et al.*, 2008). It is inevitable that trade-offs will occur between biodiversity and ecosystem service goals (chapter 2.3), but these trade-offs can be made fairly if addressed explicitly and democratically (Borrini-Feyerabend *et al.*, 2013).

Last, Indigenous Peoples and Local Communities can be integrated, along with other actors, in landscape-level governance through the recognition of both ancient practices and innovative mechanisms. The relationship between human activities and the environment also creates unique ecological, socioeconomic, and cultural patterns, and governs the distribution and abundance of local species, which are often described as cultural landscapes in western society (Farina, 2000; Plieninger & Bieling, 2012). Exemplar practices exist in other parts of the world that represent harmonious interactions between humans and the nature such as Satoyama and Satoumi of Japan, Pekarangan (homegarden) of Indonesia, Chitemene of Zambia, Malawi, and Mozambique, and are now collectively described as 'Social-Ecological Production Landscapes and Seascapes (SEPLS)' (Gu & Subramanian, 2014; Takeuchi, 2010). Similarly, the framework and designation of the Globally Important Agricultural Heritage Systems (GIAHS) by FAO since 2002 and the International Partnership for the Satoyama Initiative (IPSI) since 2010 (Box 3.1, chapter 3 for more detail) aims to identify and improve recognition about remarkable land-use systems and landscapes that have long provided various ecosystem services while contributing to biodiversity conservation and maintenance of Indigenous and local knowledge (FAO, 2010; Lu & Li, 2006; Nahuelhual *et al.*, 2014).

5.4.1.6 Telecouplings

Achieving global sustainability goals will likely require a targeted focus on the distant effects of local actions (telecouplings, such as spillover effects). Many existing environmental policy frameworks enable jurisdictions to meet targets by externalizing impacts to other jurisdictions (e.g., national greenhouse gas emissions and water use can and have been reduced in part by importing GHG and water-intensive agricultural commodities rather than producing them). While these allowances may have benefits, global sustainability will require assessing, addressing, and closing these loopholes.

Background

Systems in distant places across the world are increasingly interconnected, both environmentally and socioeconomically. The term telecoupling was created to describe socioeconomic and environmental interactions between multiple coupled systems over distances (Liu *et al.*, 2013). The concept of telecoupling is a logical extension of coupled human and natural systems because it connects distant systems instead of just studying individual systems separately or comparing different systems.

Telecoupling is an umbrella concept that encompasses many distant processes, such as migration, trade, tourism, species invasion, environmental flows, foreign direct investment, and disease spread. It expands beyond distant socioeconomic processes such as globalization by explicitly and systematically including environmental dimensions, and expands beyond distant environmental processes such as teleconnection by explicitly and systematically including socioeconomic dimensions simultaneously. As such, telecoupling emphasizes reciprocal cross-scale and cross-border interactions (e.g., feedbacks). It also helps to better understand interactions among multiple distant processes (Liu *et al.*, 2015a). Many telecouplings have existed since the beginning of human history, but their speed is much faster, their extents much broader, and their impacts much larger than in the past. Furthermore, current telecouplings occur in an entirely new context with many more people and more tightly constrained resources than ever before. Telecoupling can affect biodiversity and nature's contributions to people in distant locations and across local to global scales, with profound implications for the Aichi Biodiversity Targets, Sustainable Development Goals, and the Paris Agreement.

Spillover effects have been largely overlooked. For example, for international trade, the focus has been usually on impacts on trade partners. Several studies have reported spillover effects (also called offsite effects or spatial externalities) (e.g., Halpern *et al.*, 2008; van Noordwijk *et al.*, 2004). Placing spillover effects under the telecoupling framework can facilitate holistic understanding and management of the effects, as it helps to not only uncover the effects, but also connect them with causes and agents as well as flows across all relevant systems.

Evidence

As illustrated in Supplementary Table 5.4.4, many studies have demonstrated impacts of telecouplings on nature and nature's contributions to people. International trade has substantial impacts on ecosystem services and biodiversity in exporting countries (Lenzen *et al.*, 2012). Traditional trade research has focused on socioeconomic interactions between trade partners at the national scale, with some separate studies centered on environmental impacts (e.g., DeFries *et al.*, 2010; Lambin & Meyfroidt, 2011). More recently, studies have also showed that patterns of international investments through tax havens also have a direct impact on biodiversity loss in commodity-producing regions such as the Amazon (Galaz *et al.*, 2018). Such impacts result from land conversion from natural cover such as forests to crops (Brown *et al.*, 2014), or from pollution of water or air. It is clear that importing countries obtain environmental benefits (e.g., land allocation for biodiversity conservation and restoration rather than food production) at the expense of environmental degradation in exporting countries (Galloway *et al.*, 2007; Lenzen *et al.*, 2012; Moran & Kanemoto, 2016). For example, imports of food and other goods often have associated ecological footprints in producing regions (MacDonald *et al.*, 2015).

Spillover effects occur all over the world. These effects can be positive or negative, socioeconomic and/or environmental. They can be more profound than effects within the systems being actively managed. Evidence so far indicates that spillover effects are largely negative, such as degrading distant biodiversity, ecosystems and ecosystem services. In fact, much of the environmental impacts in many nations stem from activities driven by distant demand (e.g., through the production of goods for export; Halpern *et al.*, 2008; also see 5.4.1.2). Spillover effects are so prevalent that even policies intended to enhance regional or national sustainability can be perverse by shifting pressures to other

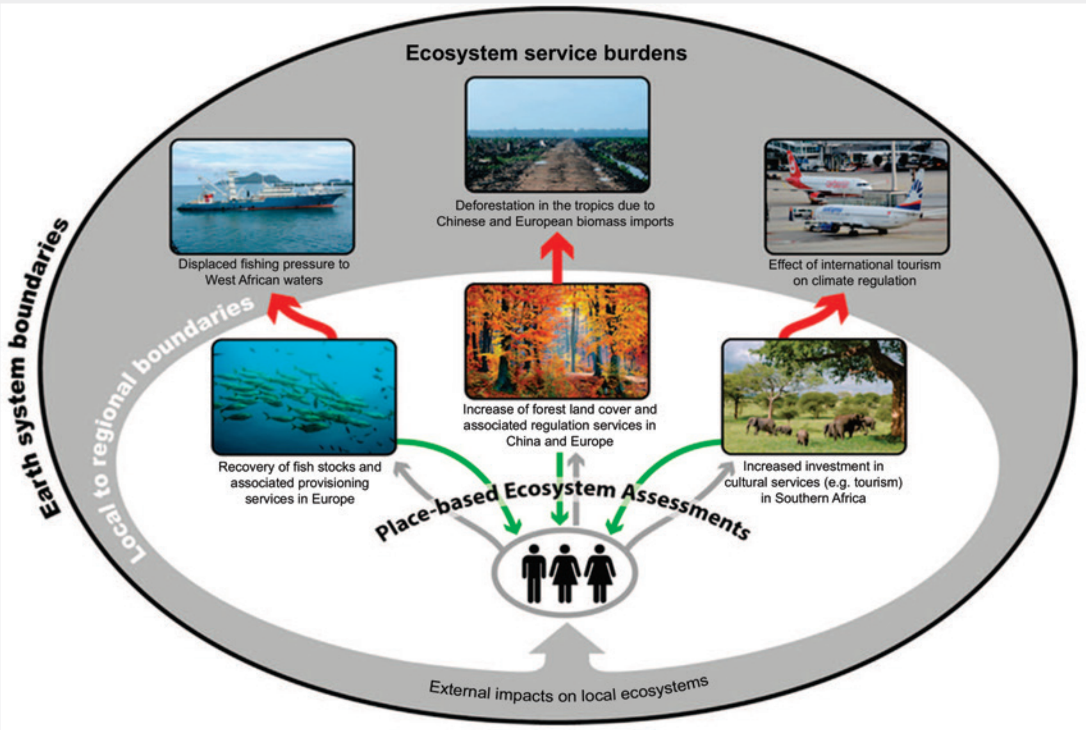

Figure 5 9 **Examples of telecoupling effects, in this case via unintended consequences associated with place-based ecosystem assessments.**

Current ecosystem services assessments focus on the benefits, trade-offs and synergies provided by ecosystem services within a delimited (often jurisdictional) boundary (green arrows) and the impacts that human activities have over such ecosystem services therein (grey arrows). Ecosystem assessments thus tend to overlook off-stage ecosystem service burdens (negative impacts on ecosystem services elsewhere; red arrows) of place-based management decisions and their feedbacks (e.g., due to climate change, bottom arrow re-entering the smaller white ellipse). Figure from Pascual *et al.* (2017b).

places (Pascual *et al.*, 2017b). Those other places may have lower environmental standards (Liu & Diamond, 2005) but richer biodiversity. For example, Sweden reduced rates of logging in Swedish forests, which increased imports from countries with greater forest biodiversity. Sweden also reduced oil use by substituting biofuels derived primarily from Brazilian sugar cane ethanol (Bolwig & Gibbon, 2009).

Even conservation efforts can generate negative spillover effects **(Figure 5.8)**. To conserve Amazonian forests, two supply-chain agreements (i.e., the Soy Moratorium and zero-deforestation beef agreements) have been implemented in the Amazon. Their implementation has substantially reduced deforestation in the Amazon but increased deforestation in the Cerrado (e.g., a 6.6-fold increase in Tocantins State of the Cerrado) (Dou *et al.*, 2018). The US and European Union countries implemented biofuel mandates to reduce their domestic carbon footprints, but these significantly changed land use and increased carbon footprints elsewhere (e.g., Africa, Asia) (Liu *et al.*, 2013).

Possible points of action

International agreements such as the Convention on International Trade in Endangered Species Flora and Fauna (CITES) and Reducing Emissions from Deforestation and Forest Degradation (REDD+) deal with distant interactions (e.g. trade), but could do so more effectively (Liu *et al.*, 2013). For example, telecoupling effects could be systematically integrated into processes of evaluating and revising the Convention and REDD+. Parties who are responsible for telecoupling effects can be identified and held accountable for negative effects (e.g., providing payment or compensation). New agreements may be needed to incorporate telecoupling effects.

Trade policies could be refined to disincentivize trade that entails negative spillover effects. Policies might restrict imports of products whose production entails large environmental damages (perhaps in part because the exporting country has very low environmental protection standards; Liu *et al.*, 2016). For example, the EU's Forest Law Enforcement, Governance and Trade (FLEGT, http://www.euflegt.efi.int/) bans the import of illegally harvested timber as a step to reduce spillover effects, which could be applied to other sectors. Such policies could be designed to raise standards by providing some assistance for nations lacking sufficient environmental governance regimes without punishing nations already suffering from extreme poverty.

Conservation scientists, policymakers and practitioners can also aid global sustainability by considering telecoupling effects in the design and evaluation of conservation policies, paying attention to negative effects outside focal conservation areas. Analyses of outcomes of conservation policies could include spillover effects in addition to the effects on the system in question.

5.4.1.7 Sustainable technology via social innovation and investment

Pathways to a desirable societal future entail a regime change first towards technologies that reduce environmental impacts and then towards those with net-positive impacts. These technological and social innovations must be proactive (not only reactive) and go well beyond the scope of traditional environmental protection policies. A sustainable economy fosters socio-technological systems that maintain, support and apply ecosystem services and biodiversity through different forms of nature-based solutions, including by galvanizing private, but public welfare oriented, investment in nature.

Background

"Technology" is a container term for various approaches to enhance human performance. Scientific assessments of technology neither idealize nor demonize it from an environmental perspective, but consider it as an ambivalent means of achieving particular goals (see, e.g., Davies, 2014; Walker & Shove, 2007).

Whereas technological development and innovation-friendly economies were long combined with a belief in the superiority of technological civilization over nature, insights about the indispensability of ecosystem services and their cost-effectiveness (e.g., Chichilnisky & Heal, 1998) have produced new expectations of technological innovations (see Geels *et al.*, 2015). Even though technological progress cannot be considered a panacea for global sustainability problems, it can contribute to overcoming sustainability challenges under particular circumstances. First, precaution can contribute to minimize or prevent negative or ambivalent outcomes of technologies (see 5.4.2.3; Renn, 2007). Second, shedding past dependencies on unsustainable or less-sustainable technologies contributes to promote innovations and spur new economic opportunities while avoiding pathways that collectively pose non-negligible risks of irreversible effects in ecological systems (Foxon, 2007). Third, ensuring that technological enhancements and resulting efficiency do not stimulate increases in new types of consumption of unsustainable goods or services (Allan *et al.*, 2006; Dimitropoulos, 2007; Herring & Roy, 2007; Lambin & Meyfroidt, 2011).

Industry and businesses are major drivers of ecosystem change. Such positioning highlights the potential for their role in reducing these impacts, which must go beyond marginal improvements (Scheyvens *et al.*, 2016). Earlier sections of this chapter (5.4.1.1, 5.4.1.2) address the needed decoupling of consumption from well-being. Innovations in technology and its usage can play a key role here. Beyond technology, innovation in business models and accounting procedures are central to incorporating environmental externalities into economic decisions. Furthermore, cross-sectoral partnerships and collaborative efforts (e.g., public-private impact investments for public benefit, and multi-stakeholder platforms for commodities that exist for palm oil, sugar, cotton, soy and rubber) facilitate implementation and mainstreaming in business and practice (Dyllick & Hockerts, 2002). Healthy skepticism about the execution of these is merited to guard against greenwashing (see Dauvergne & Lister, 2013), and effective design incorporating monitoring, adaptation and commitment to continued improvement can ensure real on-the-ground impact—but such efforts take time.

The particular role of the private investment sector in supporting sustainable development innovations is subject for debate, both in terms of the needed capital for technological development, and realization of alternative financial mechanisms. Historically, governments fund initiatives that generate public welfare goods, or devise policy and regulation to promote investment or facilitate growth in certain sectors, as has been seen with subsidies (e.g., 5.4.2.1). The scale of transformation and investment required to achieve the Sustainable Development Goals is not possible through government action alone (see SDG 17 on partnerships). Impact investing is a rapidly growing financial mechanism where private and public-private arrangements seek to generate both economic and social returns (Oleksiak *et al.*, 2015). Such investments may come in the form of direct support of a business or project, indirectly through funds managed by an intermediary, or green or social impact bonds. Governments and foundations are often key partners whose participation helps leverage capital from private sources, creating a multiplier effect, though questions remain as to how such arrangements can be implemented in the conservation sector when an existing commodity (such as agriculture or fisheries) is not present (Olmsted, 2016).

Evidence

Socio-technological innovations play a key role for transformations towards sustainability. From the scenario reviews and nexus analyses we know that technological advances in the food system and agriculture are central to feeding the world's future population and enhancing the conservation and sustainable use of nature (5.3.2.1) and to improving water quality and water use efficiency and increase storage (5.3.2.4). Energy production from various bioenergy systems as well as climate change adaptations depend on further socio-technological developments (5.3.2.2). Resourcing growing cities while maintaining underpinning ecosystems and their biodiversity is a complex socio-technological challenge across spatial and social scales (5.3.2.6).

Responsible investment in industries that directly influence natural resources and assessment metrics that go beyond short-term economic profitability will be critical to achieving the nature-related SDGs in particular. Given the broad scope of socio-technological systems, such responsible investment strategies can contribute to the emergence of a new techno-economic paradigm of sustainability (Perez, 2002), if incentives and regulations are reconfigured according to the socioecological underpinnings of the global economy (5.4.2.1-5). First steps have already been achieved by acknowledging that unsustainable technology poses large and potentially unforeseeable risks to the ecological embeddings of societies (Altenburg & Assmann, 2017). Though not expanded upon here, these processes need to address cultural diversity, social justice and public interests (see 5.4.1.5; Beumer *et al.*, 2018).

Transformations of various sectors (including energy technology, transportation, and built infrastructure generally) are beginning to attend to climate change considerations but have yet to address as mainstream a comprehensive suite of biodiversity and ecosystem service considerations (CBD, 2010; Cowling *et al.*, 2008); if they are not addressed directly, such nature-related considerations are likely to be further undermined by technological and sectoral evolution (Gopalakrishnan *et al.*, 2017). Increasing returns from investments in socio-technological niche innovations entail increasing risks of promoting less sustainable technologies and/or institutions, since already funded projects are treated preferentially at the expense of potentially superior alternatives (Foxon, 2007).

The 'rebound' of efficiency gains can be tackled in the transition phase of an incremental innovation by taxation, regulation or other impulses for consumption change (see, for example, Herring & Roy, 2007). Here, sociocultural framings, norms, worldviews and relational values influence the outcomes of socio-technological innovations enormously. Nevertheless, these factors remain largely overlooked in studies on sustainable socio-technological transformations (see Beumer & Martens, 2010).

Socially responsible and impact investing sectors are growing rapidly (GIIN, 2017), though environmental and conservation projects represent a fraction of impact investments; and impact investments currently represent a tiny share of global private capital markets. The limited application to date in the conservation sector is due to a lack of investable projects at scale, as well as challenges assessing and attributing impact in complex ecological systems (Olmsted, 2016). While there are a few large and headline grabbing arrangements, such as the Seychelles debt swap that will result in 400,000 km^2 of marine protected areas in the coming 5 years, such outcomes take years of negotiation and involve an array of public and private partners (NatureVest, 2018). Impact investments need not be so complex, but such examples highlight the potential scale of impact.

Possible points of action

Socio-technological sustainability innovations can be stimulated by incentives (e.g., Costello *et al.*, 2008; Mulder *et al.*, 1999; see also 5.4.2.1), but can also be initiated in real world experiments (Liedtke *et al.*, 2015; Nevens & Roorda, 2014; see also 5.2). Technological enhancements in companies can be supported by new innovation methods (Gaziulusoy *et al.*, 2013). Furthermore, implementation of a precautionary approach encourages proactive orientations towards sustainability in socio-technological innovation processes (Leach *et al.*, 2010).

Since affordability is a key to diffusion of new technologies (e.g., Mazumdar-Shaw, 2017), diverse financial instruments, including public financing and sharing technologies, contribute to overcoming unsustainable socio-technological systems rapidly (Foxon & Pearson, 2008; Stirling, 2008; Technology Executive, 2017). Public deliberation and transparent decision-making which involve experts, stakeholders and interested citizens generates social robustness of envisioned changes (Bäckstrand, 2003) and helps to avoid technological and institutional dependencies (van den Daele, 2000).

Every transformation process in which new technologies are established generates winners and losers. This is not only true for species (Egli *et al.*, 2018), but also for groups and individuals (e.g., O'Brien & Leichenko, 2010). Blockades to sustainable socio-technological solutions and lock-ins might be considered as strategies for avoiding losses of socioeconomic status. Innovative changes in technological policy and regulation and in incentive structures could deepen and accelerate steps towards sustainable socio-technological systems by simultaneously addressing both the demand for and supply of innovation (Jaffe *et al.*, 2005).

While there has been increased emphasis on sustainability reporting, and efforts such as the Global Reporting Initiative aim to streamline and facilitate reporting, climate metrics receive significant attention and the lack of emphasis on ecological systems is of particular concern (Milne & Gray, 2013). A study of corporate commitments to reduce deforestation highlight the challenges to meeting targets due to obstacles including leakage, lack of transparency, traceability, and selective adoption (Lambin *et al.*, 2018). These authors and others recommend increasing partnerships and arrangements between NGOs, businesses, and governments to co-create solutions and work to reduce impacts. The emergence of legal arrangements to loosen profit-maximizing constraints of corporations have promoted social business and investments in long-term sustainability that may not have been viable previously. As consumers and investors demand transparency, communication of impact and information-sharing can hold organizations accountable. Coordinating efforts across the public and private sector can help develop relevant policy, regulation, and incentives that provides stability and confidence for business and investors in new technology and innovation (e.g., Dauvergne & Lister, 2012). Corporate targets can incentivize innovation in supply and value chains (e.g., improving transparency with new technologies). Effective transformation on the ground may require national level intervention, for example, policies to support small producers who may not otherwise be able to transition as quickly or effectively. Voluntary public commitments permit early movers to demonstrate a business case for sustainable transitions, which can be bolstered by public sector support (e.g., Tayleur *et al.*, 2017). Full-cost accounting and policy shifts including changing accounting rules to include natural capital as an asset class have been shown to facilitate long-term investment in ecosystem services (Municipal Natural Assets Initiative, 2017).

5.4.1.8 Education and transmission of indigenous and local knowledge

Education and knowledge transmission are often heralded as a route to sustainability through maintenance or change in behaviours and attitudes, but their role in sustainability is even more fundamental, as a precursor to well-functioning societies. Further, education will only serve either role if conceived much more broadly than as imparting information. Rather, education that leads to sustainable development and enduring change in knowledge, skills, attitudes, and/or values builds from existing understandings, fosters social learning, and embraces a "whole person" approach. Environmental education can enhance values such as connectedness, care, and kinship. Transmission of indigenous and local knowledge can serve all the roles above, including maintaining invaluable knowledge and experiences about ecological processes, but it is also a keystone to cultural integrity and the maintenance of collective identity.

Evidence

Education, as the broad transmission of knowledge and capabilities, is widely recognized as essential for stable, well-functioning societies (Nussbaum, 2000; Otto & Ziegler, 2010; Sen, 1999). Thus, education—*in and of itself*—is a crucial precursor of sustainability (Sachs, 2015). Though education systems have sometimes served to inculcate particular norms and attitudes (King & McGrath, 2004), some educators and scholars have for centuries recognized and taken steps to deal with the inherent ethical complexities of teaching to develop engaged citizens (e.g., Dewey, 1975; Hug, 1980).

A brief yet crucial point is the demonstrated importance of education for girls and women. Increased rates and quality of education for girls and women correlate with higher levels of gender equity and lower birth rates, both of which are components of pathways to sustainability (UNICEF, 2003; see also 5.4.1.2 and 5.4.1.4).

Beyond the crucial importance of indigenous and local knowledge for cultural integrity and identity, ensuring the transmission of this knowledge and practices is key to sustainable pathways. Over millennia, IPLCs have developed and integrated invaluable knowledge and experiences about ecological processes, environmental management, production systems, as well as institutions supporting the sustainable use of resources (Nadasdy, 2007; Taylor, 2009; Tuck *et al.*, 2014; Turner, 2005; Vickery & Hunter, 2016). Many landscapes around the world, and much global agrobiodiversity heritage, depend on the knowledge and cultural memory held by IPLCs and other farmers, hunters, fishers, foragers, herders, and pastoralists, etc. Continued transmission of these forms of knowledge in varied and culturally appropriate ways (Cajete, 1994) maintains alternatives for managing landscapes and seascapes sustainably (5.3.2.3; 5.4.1.5).

Emerging insights from western literatures on education appear to be converging with lessons from indigenous and local knowledge transmission. As a first example, research demonstrates that the "deficit model" of education and communication, which assumes that people would think and act differently if only they had the right information, is rarely effective at creating lasting attitudinal or behavioural change (Dietz & Stern, 2002; Kollmuss & Agyeman, 2002). More effective educational approaches—those that are more likely to foster fundamental and long-term change in knowledge, skills, attitudes, and/or values—encompass prior knowledge (e.g., existing understandings), social interaction (e.g., interpersonal relationships and collective learning), and affective as well as cognitive dimensions (e.g., emotional responses to what is learned; Heimlich & Ardoin, 2008; Wals, 2011). Based on these findings, fields related to environmental education, including nature conservation education and education for sustainable development, have moved away from an "information delivery" model to more integrated models that collaboratively explore the intricate links between environmental and social equity and empower learners as change agents.

Broad education and knowledge transmission literatures have identified that effective education, including that for sustainability, involves two interrelated components: process and content. The former is crucial, but often overlooked. Process involves the ways education is carried out, in other words, the approaches and how teaching and learning occur. Diverse theories of learning emphasize different aspects of the learning process (Merrian & Bierema, 2013). A few commonalities emerge, and three aspects of learning theory (detailed below) are particularly relevant to issues of sustainability.

The first commonality of learning theory is the importance of recognizing and responding to learners' context, experience, and existing understandings. A helpful metaphor here follows directly from constructivist learning theory, understanding is constructed from and upon "blocks" of what is already known and if existing understandings must be changed, that must be dealt with, not ignored. In sustainability-related education, this concept is paramount, it coincides with the importance of locally based solutions that account for diverse contexts.

A second commonality is the role that social interaction plays in learning. This focus on social dimensions of learning takes two primary forms: the idea that much learning occurs via observing others (Bandura & Walters, 1977; Rogoff *et al.*, 2003) and the idea that learning occurs collectively, in and by social groups (Rogoff, 1994; Wals, 2007). These social interactions may be particularly important for the transmission of indigenous and local knowledge (Berkes & Turner, 2006; Turner & Turner, 2008). The importance of social interaction for sustainability education manifests in many ways, including the strong role that social norms play in fostering sustainable behaviour (Miller & Prentice, 2016) and the substantial success of initiatives that engage social learning for sustainability (Wals, 2007).

A third commonality addresses the relevance of attending to the "whole person" in learning. The whole person approach emphasizes that education is about both cognitive and affective aspects of the learner, that education must think not only about cognitive development, but must also attend to the crucial role that emotion can play in learning (Podger *et al.*, 2010). This holistic approach has been central to education in IPLCs for millennia. These emotional aspects may be particularly important in sustainability-related education, which can involve strong emotions such as despair and hope (Hicks, 1998; Li & Monroe, 2017; Newman, 1996).

Content is the second pillar of sustainability education. Though content may seem more straightforward than process, decisions about content, what to include and exclude from educational initiatives, are crucial. Content encompasses knowledge, concepts, and skills that are relevant to sustainability. Content that is central to most recent frameworks of environmental and sustainability education includes the following: social justice and the centrality of equity to sustainability; participatory learning and engagement with local communities (both ecological and social); citizenship skills, such as knowledge and empowerment related to collaboration, dialogue, and democratic processes; interconnectedness and systems thinking; and attention to multiple scales (spatial, temporal, and organizational) (Tilbury, 2011).

Possible points of action

Given that a common challenge to sustainable behaviour is that people default to decision-making based only on technological or economic feasibility, sustainability-related education can develop understanding of the complexities of, and synergies between, the issues threatening planetary sustainability, and encourage consideration of complex options and trade-offs. The long timescales over which people's orientations and priorities become established, coupled with the many social and personal influences on these orientations and priorities, make study of the impact of sustainability-related education difficult. Even so, research suggests that time spent during childhood in outdoor or natural environments with respected adults can be an important motivator for learning about these complex issues and taking sustainability-related action in adulthood (Chawla & Cushing, 2007). Though results about the relations between connection to nature and behaviour are varied; connection to nature, which is often but not always established in childhood, in some cases correlates with increased pro-environmental behaviour (Geng *et al.*, 2015; Gosling & Williams, 2010; Mayer *et al.*, 2008).

For IPLCs, the educational system can be the basis for strengthening a political and cultural project that incorporates traditional and novel perspectives on management, use, and maintenance of existing resources in these communities. Some see an urgent need to recognize the importance and enhance the transmission of indigenous and local knowledge, both intergenerationally and among different societal groups, as a complement to mainstream education—including to maintain crucial relationships with nature and values of responsibility and stewardship associated with those (Chan *et al.*, 2016; Chan & Satterfield, 2016). Ideally, these two forms of knowledge can be integrated, but often formal education tends to be favoured and in some cases negates the value of local forms of knowledge. Education targeted at IPLCs can develop skills required to, for example, serve in government roles or innovate in fields such as production, trade, and management, *while maintaining traditions, values and culture*. At the same time, incorporating principles and content from indigenous and local knowledge would enrich and improve all education (McCarter *et al.*, 2014; World Bank, 2015).

Environmental education can lead to a variety of outcomes supportive of sustainability, including knowledge, attitudes, and skills (Stern *et al.*, 2014). It can also enhance values such as of connectedness, care, and kinship (Britto dos Santos & Gould, 2018). That said, the fields of environmental and sustainability education are home to many discussions of the extent to which education should explicitly encourage particular values or behaviours (Hug, 1980). Though opinions on the proper course of action differ, the most common approach is for environmental education to encourage active and informed citizenship. This citizenship inherently encompasses the ability to understand and assess one's own values (virtues and principles) and those of the society in which one lives (Tilbury, 2011). Increasing awareness of connectivity in the environmental crisis and new norms regarding interactions between humans and nature would support transformative change The goal of this work is to provide tools that allow people to engage in respectful, thoughtful, and informed negotiations toward decisions and actions that lead to a sustainable future (Huckle *et al.*, 1996; Tilbury & Wortman, 2004).

5.4.2 Levers for Sustainable Pathways

5.4.2.1 Strategic use of incentives and subsidies

Achieving SDGs and Aichi Biodiversity Targets will likely require a continued evolution of subsidies (including discontinuing harmful subsidies) and incentive programs to foster conservation and stewardship practices while cultivating appropriate norms and values. Such programs can be part of effective policy mixes, involving both positive and negative incentives through regulations and market-based instruments.

Background

While subsidies are a form of incentive, due to their prevalence as a policy tool and history of challenges, we see benefit in distinguishing them from other incentive types. Note also, that although incentive programs are often considered to trigger behaviour change by providing an incentive, a diverse body of literature strongly suggests that the incentive to conserve or restore may already exist and that 'incentive' programs may work best by removing financial and regulatory barriers (Kosoy *et al.*, 2007; Stoneham *et al.*, 2003; Wilcove & Lee, 2004).

Evidence

Many scenario and pathway analyses identified the importance of shifting incentive structures, either by removing perverse subsidies or adding new positive incentives, especially studies focused on climate action, energy systems, or water. For example, Schandl *et al.* (2016) explored the implications of imposing a global carbon price, which in their model created incentives for nations to invest in renewable energy generation. Carnicer & Peñuelas (2012) demonstrated the power of funds raised through small negative incentives, showing that a small global tax on financial transactions of 0.05% could provide funds required for widespread deployment of renewable energies. McCollum *et al.* (2012) concluded that incentive mechanisms are key to transforming the global energy system, including targeted subsidies to promote specific "no-regrets" options (e.g., microcredits and grants for low-income populations to buy low-emission biomass and low-emission biomass and Liquefied Petroleum Gas (LPG) stoves).

Subsidies and other so-called incentive programs are implemented to shift institutional and individual practices, which is a key component of successful pathways, under two conditions. The first is that such incentive programs are implemented as components of policy mixes (Barton *et al.*, 2014; Bennear & Stavins, 2007; Porras *et al.*, 2011), in which regulations are also employed to set norms and provide negative incentives. In some contexts, the incentive program or subsidy is the positive element that makes a regulation politically feasible, where the regulation is the key factor in shifting practice—e.g., as apparently the case for the national payments for environmental services (PES, or 'PSA' in Spanish) program and deforestation ban in Costa Rica (Daniels *et al.*, 2010; Fagan *et al.*, 2013; Legrand *et al.*, 2013; Morse *et al.*, 2009; Pfaff *et al.*, 2009; Porras *et al.*, 2013; Robalino *et al.*, 2015).

Incentive programs play especially helpful roles in pathways when executed so as to avoid the historic pitfalls resulting in adverse environmental consequences. The evidence from natural and social sciences reveals two broad classes of failings with regard to the role of incentives and subsidies in resource management. First, a large number of incentives and subsidies are intended to encourage employment and production but have unintended large-scale impacts on biodiversity and ecosystem services (e.g., Milazzo, 1998; Sumaila & Pauly, 2007). In addition to direct negative effects on ecosystems, by distorting market signals to boost production, some subsidies promote overproduction that can fuel overconsumption and drive a vicious cycle (5.4.1.2, 5.4.2.1).

Subsidies are important features of major industries and their environmental impacts. Concerning marine fish biodiversity, for instance, an estimated $35 billion in subsidies (30–40% of estimated gross revenues from the sector) is provided to the global fishing sector annually. Nearly 60% of this is classified as harmful subsidies, i.e., those that ultimately stimulate over-capacity and overfishing (Heymans *et al.*, 2011; Sumaila *et al.*, 2016). Agricultural subsidies intended to stimulate growth in domestic markets and competitiveness in exports have likewise led to unintended ecological consequences. Corn subsidies for biofuel in the United States increased corn production and decreased soy, significantly increasing global soy prices, incentivizing Amazon deforestation as soy-related land conversion dramatically increased in Brazil (Laurance, 2007; Westcott, 2007).

In many cases, even incentives and subsidies that are intended to encourage conservation and stewardship behaviours can result in unintended negative effects at either individual or collective scales (Chan *et al.*, 2017b; Vatn, 2010). A good example here are so-called buyback or decommissioning subsidies. Millazzo (1998) considered these to be 'green' subsidies because the goal of governments who implement buyback subsidies is to reduce fishing capacity in overfished fisheries. But what often happens is that vessels supposedly retired quickly seep back into the fishery (Holland *et al.*, 1999). Furthermore, fishers may anticipate the implementation of a buyback subsidy, which can motivate them to accumulate additional fishing capacity so they can sell it later for profit in a buyback programme (Clark *et al.*, 2005).

Incentives and subsidies intended to encourage conservation and stewardship actions can also backfire by crowding out inherent motivations and by assigning or reinforcing notions of rights and responsibilities that may be counterproductive for long-term sustainability (Chan *et al.*, 2017b; Vatn, 2010). There is strong experimental evidence that when people have inherent motivations to undertake an action beneficial for biodiversity and ecosystem services, the introduction of a monetary incentive can sometimes undermine those inherent motivations (Rode *et al.*, 2015), with potentially damaging consequences for long-term outcomes. However, incentive programs can also sometimes strengthen pre-existing motivations (i.e., 'crowd-in' inherent motivations; Rode *et al.*, 2015), and can be designed to do so while articulating and reinforcing values and norms of stewardship and responsibility (Chan *et al.*, 2017b).

Possible points of action

Strategic incentive programs are pertinent to a wide range of actors including private industry (e.g., forestry, agriculture, resource users of all kinds), NGOs, IPLCs, and governments of all kinds. Programs like payments for ecosystem services (PES) can be initiated by a wide range of actors for private gain and also improved environmental outcomes (Chan *et al.*, 2017a).

Programs providing incentives to undertake positive actions may be less prone to perverse consequences than those incentivizing stakeholders to refrain from taking damaging actions. Programs designed as flexible grants and awards may be more successful at articulating socially desirable rights and responsibilities, and 'crowding in' inherent motivations, than those that provide set payments for particular metrics (e.g., trees planted or not harvested) (Chan *et al.*, 2017a).

On a general level, the rules and regulations governing day-to-day decision-making can be adapted to create the right incentive structure for transformative changes (PBL, 2012). This would include abolishing perverse incentives (e.g., capacity enhancing subsidies: Sumaila *et al.*, 2016; Sumaila & Pauly, 2007; WBCSD, 2010) and introducing environmental factors in current pricing systems, e.g., green taxation (e.g., Daugbjerg & Pedersen, 2004).

5.4.2.2 Integrated management and cross-sectoral cooperation

Integrated management is widely recognized as an important mechanism to realize co-benefits and avoid trade-offs among competing priorities involving food, biodiversity conservation, freshwater, oceans and coasts, cities and energy, as analysed above (5.3.2). Achieving multiple SDGs and Aichi Biodiversity Targets entails policy coherence and the mainstreaming of environmental objectives across institutions within and among jurisdictions (e.g., fishing, transportation, shipping, oil and gas, renewable energy). Not all action towards a given objective will simultaneously benefit all other objectives, so an integrated approach enables harmonization that achieves targets without undermining others. Additionally, achieving global objectives will take coordinated action among disparate governing bodies.

Evidence

Almost all reviewed scenario and pathway studies called for integration and harmonization of policies and programs across sectors, agencies or jurisdictions. As an example, Fricko *et al.* (2016) concluded that an integrated approach to developing water, energy and climate policy is needed, especially given anticipated rapid growth in demand for energy and water. Quite differently, McCollum *et al.* (2012) included one pathway with integrated implementation of energy efficiency measures across all major sectors, leading to substantial reduction in energy demand. Integrated management is also widely recognized as key for availability, distribution and access to water (Cosgrove & Rijsberman, 2000), including as implemented by national governments across a broad policy spectrum including agriculture, food security, energy, industry, financing, environmental protection, public health and public security (WWAP, 2015).

Environmental management typically follows a series of demarcations most often along geopolitical boundaries and human constructs of the environment. First, management agencies are often constrained by jurisdictional boundaries that do not correspond with meaningful ecological transitions (McLeod & Leslie, 2009; Tallis *et al.*, 2010). Because of telecoupling across boundaries (discussed in 5.4.1.6), integrated policy and governance is key to managing effectively. For example, the Rocky Mountains of North America are managed by different countries' natural resources, environment and parks agencies (Canada and the USA), and by different provinces and states within these countries, without overarching agencies to consider management across these divisions. Cross-jurisdictional efforts like the Yellowstone to Yukon Conservation Initiative are important for gathering a wide range of stakeholders across this large region; transboundary management would go further, reconciling multiple management goals from multiple agencies for the Rocky Mountains (Levesque, 2001).

Second, ecosystems are often managed, and studied, separately (O'Neill, 2001). Perhaps the most prominent example of this type of division is the separate management of oceans versus land (Álvarez-Romero *et al.*, 2011). Despite clearly important connections in the land-sea interface—terrestrial processes affect oceans and marine processes affect the land (Álvarez-Romero *et al.*, 2011; Hocking & Reynolds, 2011; Tallis, 2009)—these divisions persist.

Third, management is often conducted separately on different important human uses, such as government departments dedicated to parks, protected species, fisheries, agriculture, energy and development (Becklumb, 2013). In some cases, this means that environmental impacts of overlapping human activities are managed separately; in other cases (e.g., protected areas), multiple activities are managed simultaneously, but often only within tight boundaries whereas environmental impacts transcend these. Environmental impacts and risks often stem from a variety of different activities, but accumulate (Halpern *et al.*, 2008). By dividing environment management according to different uses and different goals, important interactions among ecosystem components may be ignored. For example, management plans targeting recovery of predators or higher trophic level fisheries will be more effective if management also targets recovery of prey species (Samhouri *et al.*, 2017).

Finally, paradigms of environmental management are marked by conceptual divisions, whose integration would also help achieve sustainability objectives. For decades, western environmental management has treated human interaction with the environment mainly as a source of negative impacts, when in fact humans are in many cases integral components beneficial to ecosystems functioning (Hendry *et al.*, 2017; Higgs, 2017). Human activities often can transform otherwise inhospitable ecosystems to productive food growing habitats (Higgs, 2017), and fishing activities, if regulated, can sustain fish populations for harvest (Dowie, 2009; Jacobsen *et al.*, 2017). Yet, the view that humans are exogenous to natural systems has led to a series of important negative effects. As discussed above (5.4.1.5), there are numerous examples of conservation and management agencies, with power and authority over local institutions, that have moved to displace local populations from the ecosystems that, in many cases, are conserved because of them (Dowie, 2009), discrediting local knowledge about ecosystems management (Fischer, 2000), and imposing top-down regulations over institutions that have co-evolved with local ecosystem dynamics (Ostrom, 1990). Management mechanisms to attend to local concerns and integrate local knowledge can both provide valuable information and increase legitimacy and effectiveness of management.

Siloed management explicitly excludes interactions that can affect management goals. One example is the independent management of shipping, energy production, and coastal development, and the cumulative impacts this has had on the southern resident orca ('killer whale') population (Ayres *et al.*, 2012; Murray *et al.*, 2016) in the Salish Sea (in southeastern British Columbia, Canada and northern Washington State, USA). Incorporating risks to species and systems that these whales depend on can greatly increase understanding of risk (e.g., Murray *et al.*, 2016). In most cases, however, knowledge of risks to ecosystem services deriving from different human activities and infrastructure is piecemeal and insufficient for ecosystem-based management (Mach *et al.*, 2015). For long-term sustainability of resources and environments, cross-sectoral management is key to addressing multiple goals (Harrison *et al.*, 2018).

Recent analysis of interrelationships between SDG targets provides insights into how to integrate policy towards achieving multiple goals. For instance, it suggests that achieving the ocean targets within SDG 14 has the potential to contribute to all other SDGs (Singh *et al.*, 2018). Moreover, ending overfishing and illegal fishing alone (SDG 14.4) can contribute to several other SDG targets. Increasing economic benefits to Small Island Developing States (SDG 14.7) could contribute to a suite of SDGs, depending on policy implementation and how benefits are distributed (e.g., whether marine development helps fund education (5.4.1.8)). In contrast, increasing the coverage of marine protected areas (SDG 14.5) can trigger trade-offs with other SDGs among the SDG 14 targets, because MPAs can limit access to needed local resources and decrease local peoples political power. However, these trade-offs can be avoided through proper consultation and implementation with local people (5.4.1.5), as in integrative policy planning.

Thus, integrated management is widely understood as a key mechanism to account for interactions, trade-offs and synergies between SDGs. Global scenarios underline this even though many challenges are beyond the capability of integrated assessment models (IAMs) and require additional consideration (e.g., globalization processes such as trade, migration or large-scale land acquisitions including land-grabbing).

Possible points of action

Integrating management across sectors is pertinent to a wide range of actors including private industry (e.g., forestry, agriculture, resource users of all kinds), NGOs (e.g., land trusts), IPLCs, and governments of all kinds. For example, diversified but integrated business models for forestry or farming operations may yield greater and more stable revenues as well as long-term environmental benefits (harvesting resources but also hosting tourists and other recreators, and participating in ecosystem service markets and incentive programs). However, integrated management approaches will be much more likely when encouraged or required by underlying regulations and influential private and NGO actors (e.g., insurance and reinsurance companies, companies exerting control over value chains, investors, lenders, certification systems and other standards).

Management efforts with cross-boundary provisions are often helpful (Levesque, 2001; McLeod & Leslie, 2009; Tallis *et al.*, 2010). Management across boundaries can also contribute to and benefit from Sustainable Development Goal target 17.16 (global partnerships for sustainable development, complemented by multi-stakeholder partnerships).

Laws requiring that management and policy (including protected areas and restoration efforts) state and reflect important spatial and temporal social-ecological dynamics may enable long-term cross-sectoral benefits (Kliot *et al.*, 2001; McLeod & Leslie, 2009).

Co-management arrangements and partnerships with informal environmental experts and users, may enable integration of important and time-sensitive information, enhancing legitimacy of and compliance for management plans (Dowie, 2009; Fischer, 2000).

Management plans may be more successful if they reflect multiple goals, potentially including the state of a resource/population as well as the uses of that resource (Lindenmayer *et al.*, 2000; McLeod & Leslie, 2009; Rice & Rochet, 2005).

5.4.2.3 Pre-emptive action and precaution in response to emerging threats

Sustainable pathways generally entail addressing risks well before system-specific proof of impact has been established.

Evidence

The scenario and pathway studies consulted involve a timely response to a variety of risks facing biodiversity and ecosystem services, either explicitly or implicitly. While scenarios do not generally detail the process of scientific study or the demonstration of proof, based on the long time lag between scientific focus on a phenomenon and consensus about causality, let alone proof (Oreskes, 2004), we can infer that most scenarios entail managing risky activities before establishment of proof that those activities cause particular harms. Furthermore, backcasting studies sometimes indicate that certain interventions require early implementation (Brunner *et al.*, 2016).

The need for early, precautionary action is also supported by arguments from theory, supported by a wide range of associated evidence. Many important challenges facing nature and its contributions to people involve several key complications of complex adaptive systems (numerous time-lags in social and ecological subsystems, multi-causality that impedes proof, and nonlinear responses that may appear slow until a threshold is passed, after which reversal may be impossible or impracticable; for more, see 5.4.2.4). These complications mean that empirical demonstration of system-specific cause-and-effect relationships is difficult (sometimes impossible), that it may take a long time, and that major and near-irreversible harms may have occurred before proof is established (e.g., Burgess *et al.*, 2013).

The various components of this argument from theory have considerable empirical backing. First, there is abundant evidence of time lags between ecological degradation and their societal consequences (e.g., Jackson *et al.*, 2001). This is exacerbated by interacting regime shifts at multiple scales (Leadley *et al.*, 2014). Second, ample evidence demonstrates that many changes in biodiversity and ecosystem services are the result of simultaneous action of diverse processes operating at multiple scales, which would impede the demonstration of any one factor as the cause of a given decline (e.g., Graham *et al.*, 2013; Levin, 1992; Marmorek *et al.*, 2011; Schindler *et al.*, 2003). Third, many systems exhibit thresholds (e.g., Folke *et al.*, 2004; Hastings & Wysham, 2010) combined with path-dependency (hysteresis, e.g., Graham *et al.*, 2015; Hughes *et al.*, 2010), which are difficult to reverse (Walker & Meyers, 2004) and the difficulty reducing stressors sufficiently to encourage reversal (Graham *et al.*, 2013).

This drawback of reactive management is particularly relevant for managing effects on “slow” system variables (variables that historically would generally have changed slowly, on evolutionary timescales), such as habitat availability. Such “slow” variables are often secondary concerns for stakeholders and managers more concerned with “fast” variables, such as annual fishery productivity, except where the habitat itself is widely appreciated (e.g., coral reefs; Pratchett *et al.*, 2014). However, should a slow variable pass a threshold, the system may shift rapidly to an alternate state, thus changing the dynamics of fast variables (Walker *et al.*, 2012). In such situations, even if the slow variable is restored to its previous level, the fast variables may be unable to return to their previous configurations due to the effects of path dependency.

The management of risks to slow variables is a key aspect of governing for resilience (Folke *et al.*, 2004; see also 5.4.2.4). However, as indicated above, it can be very costly if management waits for system change before acting to identify and manage risks. Due to their generally slower rates of change and susceptibility to threshold effects, slow variables in particular may often require precautionary approaches. This is the rationale for this specific lever as an issue that is separate but complementary to both integrated management (5.4.2.2) and management for resilience, adaptation, and transformation (5.4.2.4).

Possible points of action

Based on the above, it would appear that management, policies, and laws that place a strong burden of proof for the establishment of harm before requiring action are not conducive to long-term sustainability. Accordingly, a precautionary approach can be embedded in resource management and a diverse set of environmental policies and laws (e.g., Europe’s Registration, Evaluation, and Authorization of CHemicals (REACH) regulations). This point is pertinent to a wide range of actors including private industry (e.g., forestry, agriculture, resource users of all kinds), NGOs (e.g., land trusts), IPLCs, and governments of all kinds. However, precautionary approaches will be much more likely when encouraged or required by underlying regulations and influential private and NGO actors (e.g., insurance and reinsurance companies, companies exerting control over value chains, investors, lenders, certification systems and other standards).

Precautionary approaches have been subject of much debate (Stirling, 2007), but they have become accepted aspects of management in some respects. A precautionary approach is one of the principles of the UN’s voluntary Code of Conduct for Responsible Fisheries, for example, and thus has become established as a commonly invoked tenet of fisheries management. In the Alaska groundfish fisheries, for example, precaution has been integrated into the process by which allowable catches are determined, with estimates of maximum yield serving as a limit to be avoided rather than a target to be achieved; allowable catches are reduced from this limit following a series of steps that buffer against uncertainty, requiring greater reductions in catches in situations of less information (Witherell *et al.*, 2000).

A key precautionary mechanism is the maintenance of diversity. For instance, genetic diversity within and among species contributes substantially to ecosystem services, just as a diversity of species do. Genetic diversity within species maintains the potential for them to respond adaptively to environmental changes, thus facilitating and improving persistence in the face of environmental change. Diversity also maintains options for the future (NCP18).

The precautionary approach was not necessarily formulated to address issues of complex adaptive system management. However, it does provide a framework for the management of risks and uncertainty associated with complex social-ecological systems (Levin *et al.*, 2013), and thus represents an existing policy lever by which the challenges of complex adaptive system management may be addressed. Integrated Ecosystem Assessment may be useful for identifying appropriate early and pre-emptive actions (Levin & Möllmann, 2015), via a formal synthesis and quantitative analysis of relevant natural and socioeconomic factors in relation to specified ecosystem management objectives. Regardless, it is particularly important to avoid inaction (DeFries & Nagendra, 2017).

5.4.2.4 Management for resilience, uncertainty, adaptation, and transformation

Policies, programs and management agencies that seek optimal outcomes while assuming linear or equilibrium ecosystem dynamics are likely to result in undesirable surprises, as nature often operates in nonlinear ways. Policies and programs that are designed to be robust to uncertainty and to cultivate system resilience, including at the expense of program efficiency, may be more effective and efficient in the long term.

Evidence

Environmental management that seeks to maximize the extraction of a resource or population often backfires. System shocks and sudden changes can and generally will undermine effective management (Chapin III *et al.*, 2009). There are three ways in which the long term stability of an ecosystem can change that affect nature's contributions to people.

First, the consequences of ecological degradation may not be felt immediately but may manifest after a time lag. Historical overfishing has been linked to the collapse of coastal ecosystems, limiting their ability to provide resources for people (Jackson *et al.*, 2001). Similarly, the historic culling of wolves in North America has led to an abundance of coyotes and mesopredators, which has led to economic costs for ranching through predation on livestock (Prugh *et al.*, 2009).

Second, management to optimize a single goal can leave ecosystems vulnerable to disturbances. The literature on agriculture and forestry industry is replete with evidence of how management to maximize yield renders ecosystems vulnerable to pests and diseases (Meehan & Gratton, 2015; Taylor & Carroll, 2003). Future shocks to ecosystems in the form of invasive species and diseases can pose long term risks to managed ecosystems. The mountain pine beetle epidemic is a prime example, where management of forest landscapes for a single primary goal (timber extraction) resulted in monocultures of even-aged trees that facilitated a massive infestation that threatened both forest ecosystems and the forestry industry in western North America (Li *et al.*, 2005; Safranyik & Carroll, 2006). Often, this vulnerability to disturbance is due to managing ecosystems with little species and structural diversity (Meehan & Gratton, 2015). Conversely, there is ample evidence to show that incorporating ecological diversity in managed ecosystems can protect against diverse shocks and help maintain ecosystem services (Duffy, 2009; Oliver *et al.*, 2015; Tilman *et al.*, 2006a).

Third, many systems exhibit thresholds of change, meaning that the build-up of human pressure may lead to sudden large changes in an ecosystem (Boettiger & Hastings, 2013). These 'tipping points' and ecosystem state changes have been documented on land and sea (Folke *et al.*, 2004; Hastings & Wysham, 2010), and may be accompanied by 'hysteresis effects', whereby a change in ecosystem state is difficult to reverse because of path-dependency (Graham *et al.*, 2015; Hughes *et al.*, 2010; Walker & Meyers, 2004; see also 5.4.2.3). Ecological state changes can occur at multiple scales and interact, which only increases their severity and difficulty in reversing (Leadley *et al.*, 2014), increasing the importance of managing more broadly for resilience, transformation and uncertainty.

Many case studies point to state changes being a result of multiple processes operating at multiple scales, impeding the identification of any single factor as the cause of a deleterious change (Graham *et al.*, 2013; Levin, 1992; Schindler *et al.*, 2003). Changes to Earth's climate, landscapes, and seascapes are the result of a growing human imprint, and the cumulative impacts of human actions can be more important as drivers of change than any single action (Halpern *et al.*, 2015). Research on the major drivers of tipping points for ecosystems and ecosystem services often points to interactions between emerging climate change and local human pressures, indicating that some risks posed by dramatic ecological changes may be more prevalent in the future (Halpern *et al.*, 2015; Rocha *et al.*, 2015). Thus, management that explicitly accounts for nonlinear dynamics will be more important than ever.

Possible points of action

Management that includes goals to reduce vulnerability to long term shocks and tipping points may be more effective at preventing or mitigating disasters, thus reducing the waste of resources associated with recovery efforts and accruing private benefits as well as more diffuse public ones (both social and ecological). In contrast, management focused principally on optimizing resources or populations may achieve short-term gains at the expense of long-term productivity and stability.

As with early action (5.4.2.3), managing for resilience, uncertainty, adaptation and transformation is pertinent to a wide range of actors including private industry (e.g., forestry, agriculture, resource users of all kinds), NGOs (e.g., land trusts), IPLCs, and governments of all kinds. Again, resilience-focused approaches will be much more likely when encouraged or required by underlying regulations and influential private and NGO actors (e.g., insurance and reinsurance companies, companies exerting control over value chains, investors, lenders, certification systems and other standards).

Management may be more effective if it explicitly considers how the underlying ecology and physical processes support specific management goals, and the major threats to these goals (Kelly *et al.*, 2015). The consideration of nonlinear ecosystem dynamics provides vital insights into appropriate timings, windows of opportunities and risks and the financial viability of investments in ecosystem management (Sietz *et al.*, 2017). For example, by linking nonlinear ecosystem behaviour to an economic evaluation of land management options, opportunities and challenges have been presented for cost-efficiently restoring or maintaining land ecosystems that are rich in biodiversity and help to mitigate climate change. Additionally, adapting to detrimental changes will require an understanding of how ecological change affects socioeconomic conditions, and effective ways that people in specific contexts can cope with changes, such as modifying growing seasons in response to climate change, or understanding how environmental change affects the ability of indigenous groups to harvest in traditional manners (Savo *et al.*, 2016).

Inherent and systemic uncertainties (time lags, tipping points, interacting mechanisms of change) imply that management can benefit from an adaptive process, whereby learning from ongoing management actions reduce uncertainty and refine management goals (Armitage *et al.*, 2009; Walters, 1986). The "learning by doing" approach of adaptive management is effective in many instances as a operational strategy to managing under uncertainty.

Biggs *et al.* (2012) offer a set of general recommendations for building resilience of ecosystem services, including maintaining diversity and redundancy in both ecological and governance aspects; understanding and managing connectivity, recognizing that there may also be negative effects like disease; managing feedback mechanisms and 'slow' variables important to nature's contributions to people, including monitoring and adaptive management; accounting for complexity in scenarios and planning, including nonlinearity and critical thresholds; promoting learning, participation, and polycentric governance; and enabling the self-organization of agents of change.

5.4.2.5 Rule of law and implementation of environmental policies

Strengthening the rule of law is a vital prerequisite to reducing biodiversity loss and protecting human and ecosystem health (and thus the interests of the public and future generations from incursion by private interests). Stronger international laws, constitutions, and domestic environmental law and policy frameworks, as well as improved implementation and enforcement of existing ones, are necessary to protect nature and its contributions to people. Respecting differences in context, much can be learned from legislation, policies, and instruments with demonstrated successes, while still maintaining opportunities for regulatory experimentation and innovation.

Background

Over the past fifty years, every nation in the world has ratified international environmental laws, passed environmental laws, and developed environmental policies (see for instance chapters 3 and 6). In some countries, these rules have contributed to substantial progress on particular issues. In other countries, these rules have had little or no discernible effect. Despite a proliferation of both international and domestic environmental laws, global environmental problems, including biodiversity loss, climate change, and the breaching of planetary boundaries, continue to worsen.

Evidence

Good governance, respect for the rule of law, and reducing corruption are prerequisites to sustainable development (Morita & Zaelke, 2005). There is a strong correlation between a country's performance on the Rule of Law Index (World Justice Project, 2016) and the Environmental Performance Index (Yale Center for Environmental Law and Policy *et al.*, 2016). For example, the top ten countries in the Rule of Law Index have an average ranking on the EPI of 14.6, while the bottom ten countries in the Rule of Law Index have an average EPI ranking of 126.5 (World Justice Project, 2016; Yale Center for Environmental Law and Policy *et al.*, 2016). From tackling illegal logging to implementing biodiversity laws, strengthening the rule of law is essential (Schmitz, 2016; Wang & McBeath, 2017).

It is widely acknowledged that international agreements intended to protect the planet's ozone layer, beginning with the Vienna Convention for the Protection of the Ozone Layer in 1985, have succeeded in addressing this threat to biodiversity (Fabian & Dameris, 2014). However, international treaties on biodiversity and climate change, while contributing to progress in some areas, have fallen short of achieving their objectives (Kim & Mackey, 2014; Le Prestre, 2017; Rosen, 2015).

Constitutional protections for nature, biodiversity, and endangered species have contributed to conservation successes (Boyd, 2011; Daly & May, 2016; Jeffords & Minkler, 2016). Specific examples include Brazil's extensive constitutional environmental provisions (Mattei & Boratti, 2017), Bhutan's requirement that 60 per cent of forests be protected (Bruggeman *et al.*, 2016), and Ecuador's recognition of the rights of nature (Kauffman & Martin, 2017).

Strong laws intended to protect endangered species (e.g., US Endangered Species Act, Costa Rica's Biodiversity Act) have the potential to not only stem the decline of individual species but also achieve their recovery to healthy population levels (Suckling *et al.*, 2012). Weaker laws (e.g., Canada's Species at Risk Act, Australia's Environment Protection and Biodiversity Conservation Act), less rigorously implemented and enforced, are less likely to achieve recovery goals (Hutchings *et al.*, 2016; McDonald *et al.*, 2015; Mooers *et al.*, 2010; Waples *et al.*, 2013). Policies and programs also have an important complementary role in protecting biodiversity, from monitoring and evaluating wildlife populations to conservation agreements with landowners.

Effective management of human activities within protected areas is also vital to conserving biological diversity (Watson *et al.*, 2014). This applies to the regulation of both legal activities (e.g. ecotourism, recreation) and illegal activities (e.g. poaching, industrial resource exploitation).

Possible points of action

The many scenarios evaluated here recognize that, over the long-term, transformation involves legislations (and incentives) that nurture a shift from linear to circular economies (that is from pathways by which resources are extracted, manufactured into goods, then lost as waste to circular ones based on natural systems that recycle, re-use, and re-create with no waste). This is crucial for several leverage points (5.4.1.2, 5.4.1.6, 5.4.1.7). Innovative legislation and policies approaches to fostering circular economies are appearing in places as diverse as Ontario, the EU, Japan, and China (Ghisellini *et al.*, 2016). These regulatory tools would of course include laws and policies that support the shift from fossil fuels to renewable energy (Fischer & Fox, 2012; Jaffe *et al.*, 2005; Raymond, 2016).

Constitutions have particular force, and their possible amendments can help convey that governments, businesses, and individuals have a responsibility to protect and conserve biodiversity, and that individuals have the right to live in a healthy and ecologically balanced environment (Boyd, 2011). We are also increasingly learning from the experiences at various scales of governance (from municipal to international) that are recognizing the rights of nature, as in Bolivia and New Zealand, and many municipalities elsewhere (Boyd, 2018).

Equally important, however, is addressing corruption in all countries, especially that directly related to the unsustainable use of natural resources. In some regions, curbing corruption alone could have significant positive impact for biodiversity (Stacey, 2018), particularly in countries that are home to biodiversity hotspots, have weak government presence, or are experiencing expansion of commodity production.

5.4.3 Putting It Together: Joint Action of Levers on Leverage Points

Although these various actions and changes may seem insurmountable when approached separately, one action may remove barriers associated with another, potentially having mutually reinforcing positive effects. Accordingly, and perhaps counterintuitively, multiple actions may be successfully undertaken more easily than individual actions, as illustrated by a series of case studies.

5.4.3.1 The Whole Is Easier than the Sum of Its Parts: Six Case Studies

Namibia, Sweden, Costa Rica, the US, the Seychelles, and New Zealand are among the countries that have successfully integrated multiple approaches in protecting biodiversity and ecosystem services. To be clear, these are only specific examples of innovative leadership to illustrate the importance of addressing multiple components and drivers affecting nature and people. There are also important examples of regulatory interventions operating at other scales and in different manners. For example, regional initiatives can have important effects, including via market-based initiatives that affect investment and industrial production by putting a price on pollution, particularly when framed around positive values of collective benefit (Raymond, 2016). Similarly, there are countless examples of local initiatives that have proven effective, from bylaws restricting pesticide use for cosmetic purposes to bans on plastic bags and other single-use plastic items.

Namibia's success with community-based conservation illustrates many of the above levers and how they can work together. Following independence from South Africa in 1990, Namibia's new government passed progressive legislation in 1996 that devolved user rights regarding nature (in particular wildlife) to local communities (5.4.2.5, Law; 5.4.1.5, Involving local communities).

This change in governance allowed communities to register their traditional lands as conservancies, providing them with both the legal right and the legal responsibility to manage their customary landholdings for the sustainable flow of benefits from wildlife and other natural resources. The proliferation of conservancies—from 4 in 1998 to 83 at present—has resulted in increased levels of financial benefits to the rural poor (Jones *et al.*, 2012; Naidoo *et al.*, 2016), recovering populations of wildlife (Naidoo *et al.*, 2011), a tremendous increase in the amount of land under conservation management (MET/NACSO, 2018), and the reconnection of a link between Indigenous Peoples and wildlife that spans thousands of years of joint history (5.4.1.2, Visions of a good quality of life). Governance decisions were the overall platform for the conservation successes that followed, with subsequent innovative linkages between local communities and international markets for tourism and plant products providing the tangible mechanisms by which local people have benefited from their natural resources (5.4.1.7, Technology and innovation; Barnes *et al.*, 2002). While community-based conservation has helped take a step towards improving the dramatic inequality between the marginalized rural poor and wealthier ranchers and urbanites in Namibia (5.4.1.4, Inequalities), considerable threats nevertheless remain that could hamper further gains. These include increased levels of human-wildlife conflict (Kahler & Gore, 2015), incentive structures (5.4.2.1) that are preventing the full sociocultural, economic, or biophysical values of wildlife from being unlocked (e.g., subsidies and political power dynamics related to livestock and mineral extraction; Muntifering *et al.*, 2017) and competing demands for land that are not evaluated in a synthetic way by governments at various levels of responsibility (5.4.2.2, Integrated management/governance). Nevertheless, the successes seen in Namibia demonstrate that conservation by local communities on their lands can lead to gains both for people and for wildlife.

Sweden has been a global leader on issues ranging from climate change to toxic substances, ranked fifth on the Yale Environmental Performance Index in 2018 (Yale Center for Environmental Law and Policy (YCELP) *et al.*, 2018), and is proactively discussing what a future without economic growth would look like (Boyd, 2015). In 1999, the Swedish Environmental Code established a goal of solving all of the country's environmental problems over the course of a single generation (Government of Sweden, 2000). Sweden has recalibrated its economy by imposing taxes on pollution, pesticides, and waste to reduce levels of these undesired items (5.4.2.1, Incentives and subsidies; 5.4.1.3, Behaviour change) (Wossink & Feitshans, 2000). Sweden has reduced sulphur dioxide emissions by ninety per cent (in part due to a tax on emissions), cut greenhouse gas emissions by more than 20 per cent since 1990 (in part due to a high carbon tax), contributing to improved quality of life (cleaner air, safer streets, better public transit, healthier people, and more comfortable buildings). Sweden's long-term goal is to be fossil fuel free by 2050. They were the first country in the world to take strong regulatory action on polybrominated diphenyl esters (PBDEs) after researchers discovered rapidly rising levels of these flame retardant chemicals in women's breast milk (5.4.2.3, Early or precautionary action) (Darnerud *et al.*, 2015). Sweden has created timelines for eliminating the use of a broad range of toxic substances including mercury, lead, carcinogens, and chemicals that harm reproduction (5.4.2.3) (Swedish Environmental Protection Agency, 2005). They consistently rank as one of the most generous countries in the world, dedicating one per cent of their annual GDP as Official Development Assistance to help the world's poorest nations (5.4.1.4, Inequalities) (OECD, 2018). This is more than three times the level of foreign aid provided by Canadian and American governments.

Recently, Sweden recognized that some of their environmental solutions actually exported problems to other countries (i.e., leakage or spillover impacts) (Swedish Environmental Protection Agency, 2011). For example, reduced levels of logging in Swedish forests were offset by rising lumber and paper imports from countries with more biodiverse forests. Declining oil use was achieved, in part, through rising imports of biofuels from Brazil, with adverse effects on tropical forests. Sweden now recognizes that today's levels of consumption in wealthy countries need to be reduced to alleviate pressure on overexploited planetary ecosystems (5.4.1.2, Consumption) (Swedish Environmental Protection Agency, 2011). To their credit, Sweden revised its goal of achieving sustainability within one generation to state "the overall goal of environmental policy [is] to hand over to the next generation a society in which the major environmental problems in Sweden have been solved, *and this should be done without increasing environmental and health problems outside Sweden's borders*" (5.4.1.6, Telecoupling; 5.4.2.5, Law) (Swedish Environmental Protection Agency, 2013). To achieve this goal, the Swedish government observed that "policy instruments and measures must be designed in such a way that Sweden does not export environmental problems" but rather solves them through changing patterns of production and consumption (5.4.1.2, Consumption; 5.4.1.6, Telecoupling) (Swedish Environmental Protection Agency, 2011).

Costa Rica is widely recognized as an environmental leader, as a result of decades of determined effort including the key turning point of constitutional recognition of the right to a healthy environment in 1994 (5.4.2.5, Law; 5.4.1.5, Human rights and Indigenous peoples' participation) (Boyd, 2011). This small Latin American nation has enacted and implemented strong laws (such as the award-winning Law on Biodiversity, which recognizes nature's intrinsic value), placed more than one quarter of its land in parks and protected areas, and reversed the trend of deforestation (5.4.2.5, Law) (Hanry-knop, 2017). Impressively, Costa

Rica produces 99% of its electricity from renewable energy sources including hydroelectricity, geothermal, wind, and solar (5.4.2.4, Managing for resilience; 5.4.1.7, Technology and innovation) (Hanry-knop, 2017). Costa Rican laws prohibit open pit mining and offshore oil and gas development (5.4.2.5, Law). The country has a national carbon tax whose revenues are dedicated to helping small-scale farmers in reforestation and habitat protection (5.4.2.1, Incentives and subsidies). This national payment for ecosystem services program that has been shown to leverage existing inherent motivations for conservation (5.4.1.3, Enlisting values) (Kosoy *et al.*, 2007).

In 1948, Costa Rica decided to disband its military and invest the money saved in education and health care (5.4.1.2, Visions of a good quality of life; 5.4.1.8, Education) (Abarca & Ramirez, 2018). The country now enjoys high levels of literacy (97.4 per cent) and long life expectancy (79.6 years) (UNDESA, 2017; UNESCO, 2018). Twenty years ago, Costa Rica's leading exports were coffee and bananas. Today Costa Rica's most valuable exports are computer chips and medical prosthetics, as corporations have located manufacturing facilities to take advantage of the country's educated workforce, clean air, and clean water. Costa Rica is the top-ranked country in the world on the Happy Planet Index, which integrates measures of life expectancy, self-rated happiness, and per capita ecological footprints (HPI, 2016). The national expression "pura vida" or the pure life, refers to achieving happiness in harmony with nature, a goal also established in the 2009 constitution of Ecuador (5.4.1.2, Visions of a good quality of life).

The effectiveness of strong legal protection for biodiversity is illustrated by the United States, which initially passed a law to protect endangered species in 1967, revised it in 1969, and introduced its most powerful elements, which remain in place today, in 1973 (5.4.2.5, Law) (Boyd, 2018). The law compelled the United States to host an international meeting intended to spark the development of a treaty to protect endangered species. The meeting led to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). In a lawsuit involving the construction of a dam that threatened and endangered fish called the snail darter, the US Supreme Court ruled that "The plain intent of Congress in enacting the *Endangered Species Act* was to halt and reverse the trend toward species extinction, whatever the cost" (5.4.2.5; U.S. Supreme Court, 1978). The law's bold regulatory power was also alienating to some landowners, however, who resented the state imposition of restrictions on individuals and firms who happened to host species at risk. Arguably, the Act's survival in Congress and its ability to garner the willing participation of landowners depended upon regulatory innovation that removed disincentives for reporting species at risk and provided incentives for protection and restoration (5.4.1.3 Values, agency; 5.4.2.1 Incentives) through the Safe Harbour Agreement and mitigation banking (Bonnie, 1999; Fox *et al.*, 2006; Fox & Nino-Murcia, 2005). These programs enabled landowners to act in accordance with pre-existing stewardship values (5.4.1.3, Values) (Wilcove & Lee, 2004).

More than 30 species have been removed from the US endangered species list because their populations have recovered, including the bald eagle, peregrine falcon, gray whale, grizzly bear, gray wolf, brown pelican, Steller sea lion, American alligator, a snake, a flycatcher, a flying squirrel, a lizard, an orchid, and a daisy (U.S. Fish & Wildlife Service, 2018). Bald eagle populations in the lower 48 states rebounded from a low of roughly 400 nesting pairs in the early 1960s to more than 10,000 today. Keys to the bald eagle's recovery include prohibitions on hunting, banning the pesticide DDT, and protecting critical habitat, such as nesting sites (5.4.2.5, Law) (Doub, 2013). The US Center for Biological Diversity identified more than 20 species whose populations increased by more than 1,000 per cent in recent decades (Suckling *et al.*, 2012). There was a 2,206% increase in nesting Atlantic green sea turtle females on Florida beaches. The California least tern enjoyed a 2,819% increase in nesting pairs. The San Miguel island fox population increased 3,830%. Numbers of the El Segundo blue butterfly increased 22,312%. Studies indicate that roughly 90% of species listed under the US Endangered Species Act are on track to meet their recovery targets by the projected deadline (Suckling *et al.*, 2012).

The Seychelles is among the world's leaders in the percentage of its land that is designated as protected, at over 42 per cent (World Bank, 2018). The Seychelles Islands amended their constitution in 1993 to recognize that citizens have the right to live in a healthy environment, and that government has a responsibility to protect the environment (5.4.2.5, Law; 5.4.1.5, Human rights) (Boyd, 2011). In a case involving the prosecution of eight individuals for unlawful possession of meat from protected species, including sea turtles and boobies, the Supreme Court of Seychelles referred to the constitutional right in interpreting the *Wild Animals and Birds Protection Act*. The court wrote: "The right to a healthy environment has become a fundamental right. In Seychelles that right extends to the Management of Marine Resources as well as protected Land or Sea Birds" (5.4.2.5, Law) (Seychelles Legal Information Institute, 2004). Seychelles was recognized by the United Nations Environment Program as a Center for Excellence in its approach towards coastal development with reference to both efforts to protect coral reefs and a successful dolphin-free tuna industry (5.4.2.2, Integrated management; 5.4.2.4, Managing for resilience) (CountryWatch, 2018). Finally, air quality in the Seychelles is ranked number one according to the Yale Environmental Performance Index (Yale Center for Environmental Law and Policy *et al.*, 2016).

New Zealand is the highest rated non-European country on the EPI, ranked 17th in 2018 (Yale Center for Environmental Law and Policy (YCELP) *et al.*, 2018). More than 32 per cent of New Zealand's land enjoys legal protection (World Bank, 2018). New Zealand is the first country in the world to pass laws that transfer ownership of land from humans to nature (5.4.2.5, Law; 5.4.1.5, Human rights and conservation) (Boyd, 2018). Two recent laws, governing the Whanganui River and an area previously designated as Te Urewera National Park, designate these natural systems as legal persons with specific rights (New Zealand Government, 2017). For example, the Te Urewera ecosystem has the right to protection of its biological diversity, ecological integrity, and cultural heritage in perpetuity (Te Urewera Act, s. 4). These innovative laws that may eventually change the way New Zealanders relate to nature, from one in which we treat nature as a commodity that we own, towards nature as a community to which we belong (5.4.1.3, Behaviour change; 5.4.2.4, Managing for resilience). In each case, the laws establish a guardian, comprised of Indigenous Maori representatives and government representatives, to ensure that nature's rights are respected and protected (5.4.1.2, Visions of a good quality of life) (Te Urewera Act, ss. 16-17). All persons exercising powers under the Te Urewera Act "must act so that, as far as possible,

(a) Te Urewera is preserved in its natural state:
(b) the indigenous ecological systems and biodiversity of Te Urewera are preserved, and introduced plants and animals are exterminated" (Te Urewera Act, s. 5)

New Zealand is also noteworthy for having changed its electoral system in 1992 from first-past-the-post to mixed-member proportional representation (5.4.2.4, Managing for resilience) (New Zealand Electoral Commission, 2014). Advantages of proportional representation include parliaments that fairly reflect the popular vote, embody diverse populations, and require a genuine majority of the votes to form a majority government. The Green Party has played a significant role in New Zealand politics since the shift to proportional representation, serving in several coalition governments and contributing to stronger environmental laws and policies (Bale & Bergman, 2006).

5.4.3.2 Initiating Transformation, before Political Will

The examples provided throughout the chapter largely illustrate the multifaceted progress that is possible given sufficient political will, which begs the question of how to initiate transformative change towards sustainable pathways in the absence of such political will. Even in the six cases above (5.4.3.1), surely the political opportunity was created in part by various actors intervening in creative ways to enable broad and focused public support (such reconstructions of historic political processes are beyond the scope of this assessment). One of the most empowering findings that emerge from the analysis of societal responses to nature and biodiversity degradation is that individual and local efforts might be scaled up to transformative change for sustainability, including as initiated by the private sector, civil society, and governments at all scales.

There are countless worthy initiatives addressing the aforementioned leverage points and levers in various ways. These efforts deserve to be commended, and they can scale up. But they can also be better aligned with our findings above (5.4.1, 5.4.2). For example, there is a great deal of attention to reforming investment and technological innovation for a low-carbon economy, but few efforts broaden beyond climate pollution to include comprehensive impacts on biodiversity and ecosystem services, as suggested above (5.4.1.6, 5.4.1.7). Addressing the leverage points obliquely or partially (e.g., only carbon) can be counterproductive, e.g., potentially incentivizing other kinds of impacts on nature.

Existing efforts can also be better integrated, so that the various efforts can together leverage sustainability rather than undercut each other. For example, efforts to change behaviours among producers or urban populations (5.4.1.3) can be designed also to support the involvement of Indigenous Peoples and Local Communities (rather than detracting or distracting from this; 5.4.1.5).

There are also three apparent gaps in current efforts. First is laying the groundwork for a broad-scale reform of subsidies and incentives, which have structural effects (5.4.2.1). Although there is recent progress with carbon pricing (Kossoy *et al.*, 2015), there are benefits to extending these efforts in several ways. These would include advocating for and ensuring that carbon prices permeate supply chains and cross-border trade (Fischer & Fox, 2012); extending beyond carbon to include water (Molle & Berkoff, 2007), land use or conversion, and other metrics of damage or threat to biodiversity and ecosystem services; and ensuring that incentive programs are designed to foster relational values, not just 'buy' behaviour change (Chan *et al.*, 2017a) (5.4.2.1). Moreover, across many nations, there is disproportionately little effort to take stock of and address the perverse ecological impacts of subsidies on production and consumption (5.4.2.1). Because of the opposition that often arises in response to such policy reform, however, in many contexts policy progress may rely upon first laying the groundwork by enabling the widespread expression and reinforcement of supporting values (5.4.1.3; see also final point).

Second, compared with environmental laws and policies, there is a dearth of attention to the structure and approach of governing institutions to ensure that they are adaptive, precautionary, and addressing the resilience of social-ecological systems (5.4.2.2, 5.4.2.3, 5.4.2.4). Multi-stakeholder non-governmental organizations—often around certification systems—offer some promise to leverage change within commodity sectors (e.g., palm oil, soy, cotton, and rubber), when power inequities are addressed (e.g., so that small-holders have a substantial voice). Such structural changes can be fundamental (e.g., Olsson *et al.*, 2008), and yet sometimes they can elicit a broader base of support or less focused opposition. Accordingly, they may present especially promising targets for advocacy and intervention, recognizing it may take persistent and prolonged engagement.

Finally, although there are many behaviour-change programs, these efforts generally encounter one of two major obstacles to fostering system transformation. Many campaigns appeal only to a small minority of self-identified environmentalists (Moisander, 2007), which can impede behaviour change among the broader public due to negative stereotypes and the narrow reach of social norms (Chan *et al.*, 2017b). Alternatively, broad systems of taxation or incentives often lack a broad base of support or conflict with existing attitudes and values, which can backfire due to widespread resentment and/or non-participation (Chan *et al.*, 2017a). The values and concerns of voting publics are often key impediments to and enablers of top-down change. Accordingly, we see a crucial opportunity in programs and approaches that seek to leverage widely held but latent values of responsibility into new social norms in environmental (and social-ecological) contexts, perhaps by empowering all people to act in accordance with those values—easily, enjoyably and inexpensively (5.4.1.3).

Thus, a key message of this chapter is the transformative potential of identifying the diverse relational values that people already hold (principles, preferences, and virtues about relationships involving nature) that are conducive to sustainability and engineering the structural and social changes that will allow the full expression and growth of those values. These values include diverse ideals of sufficiency at the centre of *notions of a good life* that don't entail runaway *consumption* (5.4.1.1, 5.4.1.2); diverse values of responsibility are central to enabling new *social norms and action* for sustainability (5.4.1.3) including through *incentives* and regimes of *innovation, technology and investment* that align with those values (5.4.2.1, 5.4.1.7); recognition of local values consistent with conservation is an important reason to *involve Indigenous Peoples and Local Communities in conservation* (5.4.1.5); *education* is key for appreciating diverse values, which are embodied in the diverse *knowledge systems* that deserve to be maintained (5.4.1.8).

5.5 CONCLUDING REMARKS

Options for sustainable pathways abound, and our analysis suggests that they are within reach, if a diverse set of actors take action to enable them. These pathways entail addressing knotty nexuses of competing human needs, including food, biodiversity conservation, freshwater, oceans and coasts, cities, and energy. Both the actions and the pathways are clearly context-specific, with a need to tailor to regional and local circumstances via inclusive participation, but there are also key commonalities across regions and nexus points.

Across and beyond the six foci, one commonality is a diverse set of 'levers' and leverage points within which outcomes for nature, its contributions to people, and human drivers can be accomplished with strategic change. Many of these levers and leverage points have been identified elsewhere, but none have been employed widely and fully. This limited uptake is, of course, due to a variety of obstacles (chapter 6), but none of these are insurmountable with time, effort, resources, coordination, creativity, strategy, and persistence.

While all levers and leverage points are important, not all need be addressed by any one project, policy, or actor. But given strong interactions (e.g., synergies and trade-offs) between various levers and leverage points, we have described how engaging several together may be easier and more effective than addressing them piecemeal (5.4.3). For example, subsidy reform (5.4.2.1) and improved policies for innovation and technology (5.4.1.7) are excellent steps alone but often ineffectual in the presence of systemic corruption or weak rule of law (5.4.2.5). Similarly, enlisting values to encourage widespread conservation (5.4.1.3) and involving Indigenous Peoples and Local Communities in landscape management (5.4.1.5) are much needed, but they cannot yield long-term achievement of nature-based goals without also reining in overconsumption (5.4.1.2), likely by engaging appropriate visions of a good quality of life (5.4.1.1).

A key constituent and outcome of the transformational pathways suggested to achieve the SDGs is the emergence of a global sustainable economy, underpinned by a networked set of sustainable societies. The SDGs and many other agreements and collective efforts are inspiring societies and nations to envision a world in which innovation, new technology, and environmentally responsible consumption evolve towards eliminating environmental impacts, diminishing inequalities, and improving human well-being. Such a world would be enabled by diverse people and organizations engaging voluntarily in conservation and restoration, where all people are accorded inherent rights to nature and celebrated for their crucial roles in maintaining that nature for distant people, future generations, and nature itself.

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Chapter 6.

OPTIONS FOR DECISION MAKERS

IPBES GLOBAL ASSESSMENT REPORT ON BIODIVERSITY AND ECOSYSTEM SERVICES
CHAPTER 6. OPTIONS FOR DECISION MAKERS

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CHAPTER **6**

OPTIONS FOR DECISION MAKERS

EXECUTIVE SUMMARY

1 The Sustainable Development Goals and the 2050 Vision for Biodiversity cannot be achieved without transformative change, the conditions for which can be put in place now *(well established)* {6.2; chapters 2, 3, 5}*.* In the short term (before 2030), all decision makers can contribute to the sustainability transformation, including through the rapid and improved deployment of existing policy instruments and new initiatives that more effectively enlist individual and collective action for transformative change, and the reform and removal of harmful existing policies and subsidies *(well established)*. Additional measures are necessary to enable transformative change in the long term (up to 2050) to address the indirect drivers that are the root causes of nature deterioration (*well established*), including changes in social, economic and technological structures within and across nations {6.2, 6.3, 6.4}.

2 Transformative change needs innovative approaches to governance. Such transformative governance can incorporate different existing approaches, such as integrative, inclusive, informed and adaptive governance. While these governance approaches have been extensively practiced and studied separately, their combined contribution to enabling transformative change has not yet been thoroughly explored (*established but incomplete)* {6.2}. Integrative approaches, such as mainstreaming across government sectors, are focused on the relationships between sectors and policies and help to ensure policy coherence and effectiveness (*well established*). Inclusive approaches help to reflect a plurality of values and ensure equity (*established but incomplete*), including through equitable sharing of benefits arising from their use and rights-based approaches (*established but incomplete*). Informed governance entails novel strategies for knowledge production and co-production that are inclusive of diverse values and knowledge systems (*established but incomplete*). Adaptive approaches, including learning from experience, monitoring and feedback loops, contribute to preparing for and managing the inevitable uncertainties and complexities associated with social and environmental changes (*established but incomplete*) {6.2}.

3 Empowering all actors can promote sustainability and ensure inclusiveness and equity. Current policies and actions for nature, nature's contributions to people (NCP) and good quality of life (GQL) often privilege elite actors and their value systems, which hampers their legitimacy and effectiveness *(well established)*. Empowerment strategies can be implemented by governments and civil society groups, and include education and information instruments, but also redistribution of power and rights so that all can assume responsibility and control over their lives and futures *(well established)*. Existing approaches such as co-management and community-based natural resource management can be effective in ensuring the equal distribution of the costs and benefits of conservation and reconciling different interests and values, provided that they recognize and address trade-offs and uneven power relations *(well established)*. Inclusiveness and equity will imply recognizing the inevitability of hard choices, costs and common responsibilities *(well established)* {6.2; 6.3; 6.4}.

4 Effective decision making for transformative change uses a mix of instruments and tools, and bridges across different sectors, levels and scales *(established but incomplete).* Since no single instrument or tool is sufficient *(well established)*, policy mixes need to be carefully tailored to – together – effectively address all direct and indirect drivers of nature deterioration **(Table 6.1)**. Sectoral policies and measures can be effective in particular contexts, but often fail to account for indirect, distant and cumulative impacts, which can have adverse effects, including exacerbating inequalities *(well established).* Cross-sectoral approaches, including landscape approaches, integrated watershed and coastal zone management, marine spatial planning, bioregional scale planning for energy and new urban planning paradigms, offer opportunities to reconcile multiple interests, values and forms of resource use, provided that these cross-sectoral approaches recognize trade-offs and uneven power relations between stakeholders (*established but incomplete*) {6.3; 6.4}.

5 Since the effectiveness of alternative actions and policies depends on the decision context, there are no generic recipes for success *(established but*

incomplete). All decision makers can contribute to enhancing the effectiveness of instruments in specific contexts over time through informed and adaptive governance approaches. The comprehensive review of the application of policy instruments presented in this chapter indicates that the implementation of many existing instruments (e.g. protected areas) can be further enhanced, while on the other hand the effectiveness and application of other instruments (e.g. information campaigns for consumers or agricultural certification schemes) requires more research. Since the effectiveness of many instruments for the conservation of nature and its contributions in different contexts is currently unknown, more research and appropriate monitoring is needed {6.3; 6.4}.

6 **Decision makers have a range of options and tools for improving the sustainability of economic and financial systems *(well established)* {6.4}. Achieving a sustainable economy involves making fundamental reforms to economic and financial systems and tackling poverty and inequality as vital parts of sustainability** *(well established)* {6.4}. Governments could reform subsidies and taxes to support nature and its contributions to people, removing perverse incentives, and instead promoting diverse instruments such as payments linked to social and environmental metrics, as appropriate *(established but incomplete)* {6.4.1}. Trade agreements and derivatives markets could be reformed to promote equity and prevent deterioration of nature, although there are uncertainties associated with implementation (*established but incomplete*) {6.4.4}. To address overconsumption, voluntary measures can be more effective when combined with additional incentives and regulation, including promotion of circular economies and sustainable production models *(well established)* {6.4.2; 6.4.3}. Although market-based policy instruments such as payments for ecosystem services, voluntary certification and biodiversity offsetting have increased in use, their effectiveness is mixed, and they are often contested; thus, they should be designed and applied carefully to avoid perverse effects in context (*established but incomplete*) {6.3.2.2; 6.3.2.5; 6.3.6.3}. Alternative models and measures of economic welfare (such as inclusive wealth accounting, natural capital accounting and degrowth models) are increasingly considered as possible approaches to balancing economic growth and conservation of nature and its contributions and recognizing trade-offs, value pluralism and long-term goals *(established but incomplete)* {6.4.5}.

7 **Recognizing the knowledge, innovations and practices, institutions and values of Indigenous Peoples and Local Communities and their inclusion and participation in environmental governance often enhances their quality of life, as well as nature conservation, restoration and sustainable use, which is relevant to broader society *(well established)* {6.2.4.4}. Governance, including customary institutions and management systems, and co-management regimes involving Indigenous Peoples and Local Communities, can be an effective way to safeguard nature and its contributions to people, incorporating locally attuned management systems and indigenous and local knowledge.** The positive contributions of Indigenous Peoples and Local Communities to sustainability can be facilitated through national recognition for land tenure, access and resource rights in accordance with national legislation{6.3.2.3}, the application of free, prior and informed consent {6.3.6}, increasing participation in resource management decision-making (including through capacity development and financial support) {6.2.4.4, 6.3.4}, and improved collaboration, fair and equitable sharing of benefits arising from the use, and co-management arrangements with Indigenous Peoples and Local Communities *(well established)* {6.2.4, 6.3.2.3}.

8 **Multi-functional landscapes consisting of mixed land systems that include intensive and extensive forms of land use are critical for food security and rural livelihoods, generate a diversity of nature's contributions to people, and can harbour considerable biodiversity (*well-established)* {6.3.2}.** At the same time, these landscapes are the space where the largest conflicts with nature take place *(well established).* Policy mixes harmonized across sectors, levels of governance and jurisdictions can account for ecological and social differences across and beyond the landscape, build on existing forms of knowledge and governance and address trade-offs between tangible and non-tangible benefits in a transparent and equitable manner *(established but incomplete).* Options for the private sector – especially local land managers – include diversified land uses and crops, including agroforestry practices, crop rotations, maintenance of semi-natural habitats, soil conservation practices and habitat restoration activities *(well established)*. Options that require the engagement of all actors related to the landscape (e.g., regional governments, producers, neighboring urban inhabitants, protected area authorities) include context-sensitive combinations of participatory approaches to resolve trade-offs and conflicts among objectives, certification schemes for landscape products, direct payments such agri-environmental schemes and PES, research on ecological intensification practices, technical outreach and information campaigns *(established but incomplete)* {6.3.2}.

9 **Feeding the world in a sustainable manner, especially in the context of climate change and population growth, entails food systems that ensure adaptive capacity, minimize environmental impacts, eliminate hunger, and contribute to human health and animal welfare *(established but incomplete)* {6.3.2.1}.** Ensuring the adaptive capacity of food production

incorporates measures that conserve the diversity of genes, varieties, cultivars, breeds, landraces and species. Essentially, this refers to further improvement and harmonization of present global mechanisms of genetic material transfers (e.g., the Nagoya Protocol, the International Treaty on Plant Genetic Resources for Food and Agriculture and the International Convention for the Protection of New Varieties of Plants*) (well established).* Options for the private sector – especially food producers – include expanding and enhancing sustainable intensification, engaging in ecological intensification and sustainable use of multi-functional landscapes, increasing focus on climate-resilient agriculture, and improving food distribution *(established but incomplete).* Options for governments at the international and national levels include regulating commodity chains, managing large-scale land acquisitions, and expanding food market transparency and price stability. Options that address and engage other actors in food systems (including the public sector, civil society and consumers, grassroot movements) include participatory on-farm research, promotion of low-impact and healthy diets and localization of food systems. Such options could help reduce food waste, overconsumption, and demand for animal products from unsustainable production, which could have synergistic benefits for human health *(established but incomplete)* {6.3.2.1}.

10 Sustainable forest management can be better achieved through promoting multifunctional, multi-use, multi-stakeholder and improving community-based approaches to forest governance and management (*well established*) {6.3.2.2}. National and subnational governments can further promote and strengthen community-based management and governance, including customary institutions and management systems, and co-management regimes involving Indigenous Peoples and Local Communities with due recognition of their knowledge and rights who manage almost one third of the forests in the Global South; and improve the conservation and sustainable use of (old-growth) forests through a combination of measures and practices, including protected and other conservation areas; sustainable management and reduced impact logging, forest certification, PES and reducing emissions from deforestation and forest degradation (REDD+); supporting reforestation and forest restoration; transparent monitoring; and addressing illegal logging *(established but incomplete).* International agencies can technically and financially support governments and other stakeholders in achieving the above, including through effective implementation of multilateral environmental agreements (MEAs) and other relevant international agreements *(well established).* Decision makers at all levels can also improve forest governance by recognizing different value systems while formulating forest policies and making management decisions and adopting informed and adaptive decision-making practices *(established but incomplete)* {6.2.4.1; 6.3.2.2; 6.3.2.3}.

11 Expanding and effectively managing the current network of protected areas, including terrestrial, freshwater and marine areas, is important for safeguarding biodiversity (*well established*), particularly in the context of climate change. Conservation outcomes also depend on adaptive governance, strong societal engagement, effective and equitable benefit-sharing mechanisms, sustained funding, and monitoring and enforcement of rules *(well established)* {6.3.2.3}. Protected areas support nature, deliver NCP and contribute to good quality life *(well established)*. National Governments play a central role in supporting primary research and effective conservation and sustainable use of multi-functional landscape and seascape. The latter include planning ecologically representative networks of interconnected protected areas to cover key biodiversity areas and managing trade-offs between societal objectives that represent diverse worldviews and multiple values of nature *(established but incomplete)*. Governance diversity, tailored to the local conditions, includes co-management schemes, local empowerment, and formal recognition of IPLCs rights over their territories *(well established).* Large-scale, proactive landscape planning, including transboundary conservation planning, helps prioritize land uses that balance nature, NCP and GQL *(well established)*. Implementation beyond protected areas includes combating wildlife and timber trafficking through effective enforcement and ensuring the legality and sustainability of trade in wildlife. Such actions include prioritizing wildlife trafficking in criminal justice systems, using community-based social marketing to reduce demand and implementing strong measures to combat corruption at all levels (*established but incomplete)* {6.3.2.3}.

12 Managing coastal and near-shore ocean management for sustainable and resilient futures, in the face of economic pressures and climate change, entails applying policy mixes, including integrated coastal planning and restoration, designation and expansion of Marine Protected Areas, control of plastic and other pollution, and reform of fishery subsidy strategies (*established but incomplete*) {6.3.3.3}. Marine protected areas (MPAs) have demonstrated success in both biodiversity conservation and improved local quality of life when managed effectively. MPAs can be further expanded through larger or more interconnected protected areas or new protected areas in currently under-represented regions and key biodiversity areas *(established but incomplete)* {6.3.3.3.1}. The fishing industry, a major source of aquatic biodiversity losses, can be supported by positive incentives and the reform and removal of harmful existing policies and subsidies to change current practices and remove derelict gear that threatens nature *(well established)* {6.3.3.3.2}. Improved surveillance and investment in scientific research are critical due to major pressures on coasts (including development, land reclamation and water pollution), implementing marine conservation outside protected areas, such as integrated coastal planning, is important for biodiversity conservation and sustainable use *(established but incomplete*) {6.3.3.3}. Other measures to expand multi-sectoral cooperation on coastal management include corporate social responsibility measures, standards for building and construction and eco-labelling (*well established*) {6.3.3.3.2, 6.3.3.3.5}. Additional tools could include economic instruments for financing conservation both non-market and market based, including for example payment for ecosystem services, biodiversity offset schemes, blue-carbon sequestration, cap-and-trade programs, green bonds and trust funds and new legal instruments {6.3.3.1.3}.

13 Governance for the oceans and high seas is currently marked by policy fragmentation leading to nature deterioration *(established but incomplete)* {6.3.3.1}. To sustain biodiversity and fisheries in the high seas, existing sectoral regulatory agencies such as shipping authorities and Regional Fisheries Management Organizations can increase the pace of mainstreaming nature into their policies *(well-established)* {6.3.3.2}. Based on the experience of regional fisheries management organisations, a strong science foundation for informed governance is essential for effective protection, although costly in terms of human resources and technology *(well established)* {6.3.3.2.2}. Cost-effectiveness can be achieved through sharing and integrating information systems across agencies and sectors (e.g., shipping, fishing, mining, and port agencies) and through collaboration between industry, governments and non-governmental organizations *(well established*) {6.3.3.1.1}. New legal instruments such as the proposed international legally binding instrument under the United Nations Convention on the Law of the Sea (UNCLOS) on the conservation and sustainable use of marine biodiversity of areas beyond national jurisdiction could accelerate national action to provide nature protection, particularly when combined with strengthened regional cooperation *(established but incomplete)* {6.3.3.3.1, 6.3.3.1.1}.

14 Inclusive water governance can promote informed decisions, facilitate stronger interaction between communities and conservation activities, and foster equity among water users (*well established*) {6.3.4}. Creating a space for stakeholder engagement and transparency in water conservation and transboundary water management can help to minimize environmental, economic and social conflicts as well as risks *(well established)* {6.3.4.3, 6.3.4.7}. Integrated freshwater management depends, *inter alia*, on recognizing the functional interdependencies between and among rural landscape management and urban demands, incorporating a regional view of the water cycle, understanding of conflicting interests for water uses, and assessing the opportunities for cooperation among users *(established but incomplete)* {6.3.4.1, 6.3.4.2, 6.3.4.6}. In the short term, collection and monitoring of data remains crucial to governments and private actors for water abstraction and management due to the interconnected nature of surface and groundwater (*well established)* {6.3.4.1}. With regard to watershed payment for ecosystem services programmes, their effectiveness and efficiency can be enhanced by acknowledging multiple values in their design, implementation and evaluation and setting up impact evaluation systems (*established but incomplete*) {6.3.4.4}. National regulatory frameworks, policy guidance, institutional arrangements, and water quality standards can set benchmarks for better performance and attract investment to improve water resources and conditions *(well established)* {6.3.4.5, 6.3.4.6}.

15 Nature-based solutions can be cost-effective for meeting the Sustainable Development Goals in cities, which are crucial for global sustainability *(established but incomplete)* {6.3.5}. Integrated urban planning can play a significant role in reducing the environmental impacts of cities and the transformation to sustainability *(well established)* {6.3.5.1, 6.3.5.3}. Nature-based approaches include safeguarding or retrofitting of green and blue infrastructure such as green spaces, water, and vegetation and tree cover into existing urban areas and in new settlements. They can contribute to flood protection, temperature regulation, urban food production, recreation, cleaning of air and water, treating wastewater and the provision of energy, locally sourced food and the health benefits of interacting with nature. They can also enhance urban biodiversity, and they can provide cost effective solutions for local climate change adaptation and promoting low carbon cities *(well established)* {6.3.5.2}. Nature-based solutions and integrated planning also enable improved access to social services, such as sanitation and housing *(well established)* {6.3.5.4}.

16 Recognizing pluralistic values and diverse interests are key to mitigating the impacts, and enabling the sustainable management of energy, mining and infrastructure *(established but incomplete)* {6.3.6}. At all levels of governance, it is crucial to integrate sustainability criteria and internalize the impacts of bioenergy projects on nature *(established but incomplete)* {6.3.6.1}. Promoting innovative financing and ensuring compensation for environmental and social impacts of energy, mining and infrastructure projects are important measures in the sustainable energy transition and responsible mining *(established but incomplete)* {6.3.6.2, 6.3.6.3, 6.3.4.6}. Community-based management and respect for the rights of Indigenous Peoples and Local Communities to land and water has emerged as a way to ensure access to clean, reliable and affordable energy *(well established)* {6.3.6.4, 6.3.6.5}. Incentive programs and policies can also aim at reducing consumption, improving energy efficiency, and supporting community-based management and decentralized sustainable energy production {6.3.6.1,6.3.6.3, 6.3.6.4,6.3.6.5}.

Table 6 1 Main options for decision makers: Instruments that can be included in smart policy mixes.

Decision maker	Instruments that can be included in smart policy mixes within or across issues {Tables 6.3, 6.4, 6.5, 6.6,			
	Landscape approaches	**Food**	**Forest**	**Conservation**
Intergovernmental organizations	Support and facilitate the development of transformative landscape governance networks together that develop policy mixes for sustainable use of multi-functional landscapes	Support and facilitate expansion and enhancement of sustainable intensification, ecological intensification and sustainable use of multi-functional landscapes Develop and harmonize agreements on genetic resources for agriculture	Improve reducing emissions from deforestation and forest degradation (REDD+) and payment for ecosystem services (PES) policies Address illegal logging and trade in illegal timber Facilitate enhanced forest monitoring	Facilitate expansion and improved management, functionality and connectivity of (transboundary) protected areas Address illegal wildlife trade Facilitate enhanced implementation of and coordination between multilateral environmental agreements Promote mainstreaming of biodiversity into other sectors Enable more financial support for conservation
Governments (national, subnational, local)	Support, facilitate and engage in transformative landscape governance networks	Encourage dietary transitions and alternate consumption Support and facilitate expansion and enhancement of sustainable intensification; ecological intensification and sustainable use of multi-functional landscapes Facilitate localization of food systems and reduction of food waste Facilitate improvement certification standards Enable conservation of genetic resources for agriculture Manage large-scale land acquisitions	Improve the conservation of (old-growth) forests Enable expansion and improvement of community-based forest management and co-management Improve REDD+ and payment for ecosystem services policies Support reduced impact logging Promote improvement and implementation of certification Support reforestation and forest restoration Address illegal logging and trade in illegal timber Enhance forest monitoring	Expand and improve management, functionality and connectivity of (transboundary) protected areas Recognize management by IPLCs and Other Effective area-based Conservation Measures Strengthen enforcement and implementation of law and multilateral environmental agreements (MEA) and address corruption Enforce free, prior and informed consent (FPIC) and recognize IPLC rights Enhance approaches to invasive alien species (IAS) management Develop participatory approaches to restoration and link restoration to revitalizing indigenous and local knowledge Raise level of financial support for conservation Mainstream biodiversity into other sectors
Non-Governmental Organizations	Engage in transformative landscape governance networks	Encourage dietary transitions and food waste reduction Engage in expansion and enhancement of sustainable intensification Engage in ecological intensification and sustainable use of multi-functional landscapes Improve certification standards	Engage in improvement of REDD+ and PES Engage in promoting and improving certification Engage in addressing illegal logging	Engage in expansion and improved management, functionality and connectivity of (transboundary) protected areas Support management by IPLCs and Other Effective area-based Conservation Measures Engage in addressing illegal wildlife trade

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Marine	Water	Cities	Energy	Sustainable economies
Implement global marine environmental agreements for shipping Promote comprehensive protection of biodiversity and ecosystem services of the High Seas Mobilize conservation funding	Address fragmentation of freshwater treaties Promote integrated water resource management and transboundary water management Strengthen rights- based approaches & freshwater standards	Promote sustainable urban planning Promote nature-based solutions and green infrastructure Promote increasing access to urban services	Develop standards for sustainable renewable energy projects Promote biodiversity inclusive environmental impact assessments	Promote sustainable production and consumption; circular economy models Reform trade system and World Trade Organization Promote reform of subsidies Promote reform of models of economic growth
Mainstream biodiversity conservation and promote ecosystem services Support shared and integrated ocean governance Promote stronger implementation of fisheries conservation measures Strengthen integrated management of coastal waters	Promote interlinkage among water-energy-food systems Develop integrated rights-based and participatory approach to water management Encourage stakeholder engagement Develop water-efficient agricultural practices Promote and facilitate nature-based solutions Restrict groundwater abstraction	Implement sustainable urban planning, including bioregional planning, biodiversity-friendly urban development, increasing green spaces, and creating space for urban agriculture Implement nature-based solutions and green infrastructure Reduce the impacts of cities by encouraging articulated density; discouraging car use and promoting public transportation; developing energy efficient building codes; and encouraging alternative business models Enhance access to urban services, including through sustainable urban water management, integrated sustainable solid waste management, incentive programs and participatory planning	Develop sustainable bioenergy strategies Strengthen and enforce biodiversity inclusive environmental impact assessment laws and guidelines Strengthen biodiversity compensation policies for development and infrastructure loss	Address over and under consumption through taxes on consumption, product labeling, discouraging overbuying, promotion of sharing economy Sustainable public procurement Reduce unsustainable production through taxes on resource consumption and degradation; promotion of circular economy models; capping of resource consumption; applying life cycle assessment Reform derivative and futures markets Reform subsidies by assessing impacts of all subsidies policies and long-term removal of all environmentally-unsound subsidies Application of alternative measures of economic welfare and Natural Capital Accounting; move towards steady state economics paradigm and degrowth agenda
Develop conservation programs to raise awareness on local ecosystems, species values and knowledge Engage stakeholders Contribute to global assessments and participate in the global standard setting Engage in developing and monitoring fishery certification schemes	Organize awareness raising activities Engage in nature-based solutions Engage in developing and monitoring water quality and abstraction related standards	Engage in sustainable urban planning Promote the reduction of the impacts of cities Engage in enhancing access to urban services	Participate in community led initiatives Engage in developing and monitoring bioenergy standards and schemes	Develop initiatives to discourage overbuying; engage in development of product labeling Promote circular economy Promote initiatives for transformation to sustainable economy

Decision maker	Instruments that can be included in smart policy mixes within or across issues {Tables 6.3, 6.4, 6.5, 6.6,				
	Landscape approaches	Food	Forest	Conservation	
Citizens, community groups, farmers	Engage in transformative landscape governance networks	Change to sustainable consumption (diet, reducing waste) Engage in localized food systems Engage in expansion and enhancement of sustainable intensification; ecological intensification and sustainable use of multi-functional landscapes Engage in conservation of genetic resources for agriculture	Engage in community-based forest management and co-management Change to sustainable consumption	Engage in conservation efforts	
Indigenous People and Local Communities	Engage in transformative landscape governance networks	Engage in conservation of genetic resources for agriculture	Engage in community-based forest management and co-management Engage in forest monitoring	Engage in management Engage in addressing illegal wildlife trade; sustainable wildlife management Engage in restoration and revitalization of indigenous and local knowledge	
Donor agencies	Support transformative landscape governance networks	Support reduction of food waste; localized food systems; sustainable intensification; ecological intensification	Support community-based forest management and co-management; improvement of REDD+ and PES policies; improvement and implementation certification; initiatives addressing illegal logging; enhanced forest monitoring	Support expansion and improved management, functionality and connectivity of (transboundary) PAs; management by IPLCs and Other Effective area-based Conservation Measures; addressing illegal wildlife trade Raise level of financial support for conservation	
Science and educational organizations	Engage in transformative landscape governance networks	Engage in expansion and enhancement of sustainable intensification and ecological intensification Engage in transformation food storage and delivery systems Facilitate conservation and sustainable use of genetic resources for agriculture	Support reduced impact logging Support improvement of certification Engage in enhancing forest monitoring	Analyze social and economic impacts of restoration Analyze conservation impacts of Official Development Assistance	
Corporate actors	Engage in transformative landscape governance networks	Contribute to expansion and enhancement of sustainable intensification Contribute to ecological intensification Transform food storage and delivery systems Improve certification standards Engage in conservation of genetic resources for agriculture	Implement reduced impact logging Engage in improvement and expansion of forest certification Address illegal logging and trade in illegal timber	Engage in addressing illegal wildlife trade Engage in restoration Raise level of financial support for conservation	

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Marine	Water	Cities	Energy	Sustainable economies
Engage in policy decision making, remedial actions, and educational programs Engage in awareness campaigns to influence consumer behaviour and consumption	Participate in ecosystem restoration activities Engage in collaborative initiatives	Engage in sustainable urban planning Engage in development and maintenance of nature-based solutions and green infrastructure Change to sustainable consumption (reduced waste, increased public transport) Engage in initiatives to access to urban services	Actively engage in community led activities	Engage in reduced consumption movements and change towards sustainable consumption; local reuse or fix-up initiatives Support companies with sustainable production models
Engage in coastal management and MPA Collaborate in integrated management of marine resources	Support co-management regime for collaborative water management Engage, where appropriate, with payment for ecosystem services or other local water ecosystem services provisioning schemes	Engage in advocacy networks for sustainable cities	Participate in formulating sustainable bioenergy strategies Engage in the implementation of Free, Prior and Informed Consent	Engage in discussions over values in a sustainable economy and good life
Support funding sources in the High Sea that ensure conservation Ensure funding promotes sustainable fishing practices Promote innovative and longer term financing through market based mechanisms	Establish standards and guidelines that improve water quality and integrate social and environmental considerations	Support sustainable urban planning Support initiatives to enhance access to urban services	Promote innovative financing for sustainable infrastructure Establish sustainable bioenergy guidelines	Support initiatives to transform to sustainable economy Fund projects on use of alternative welfare measures
Promote mainstreaming climate change adaptation and mitigation into marine and coastal governance regimes	Promote awareness raising activities	Support sustainable urban planning, development of nature-based solutions and green infrastructure, reduction of the impact of cities and enhancing access to urban services	Promote awareness raising activities	Support circular economy; further include BES in life cycle assessment Research on environmental impacts of futures and derivatives Support reform of models of economic growth
Engage in CSR activities, certification and best practices in fisheries and aquaculture production methods Mobilize conservation funding for the oceans Take account of ecological functionality into coastal infrastructure	Engage in setting water quality and abstraction related standards Engage in water restoration schemes Promote sustainable investment in water projects Invest in clean and environmentally sound technology	Engage in sustainable urban planning Develop energy efficient buildings Engage in alternative business models Engage in partnerships and other initiatives to enhance access to urban services	Engage in setting sustainable bioenergy strategies Promote sustainable infrastructure practices Strengthen biodiversity compensation policies Promote innovative financing for sustainable infrastructure	Implement sustainable sourcing practices; design for sustainability; engage in development of product labeling; apply life cycle assessment; contribute to circular economy Engage in corporate social responsibility Engage in reform of models of economic growth

6.1 INTRODUCTION

In recent decades, the extent and scope of societal responses to environmental problems, including biodiversity decline, have been extensive and diverse. The outcomes, however, have been mixed across sectors and levels of governance, with limited success in reverting global trends and in addressing the root causes of degradation. Lessons and opportunities also abound, amid new challenges and scenarios. This chapter discusses opportunities and challenges for all decision makers to advance their efforts in meeting, synergistically, internationally agreed goals for sustainable development, biodiversity conservation, and climate change mitigation and adaptation. In doing so, the chapter builds on the analysis in the previous chapters, which have identified direct and indirect drivers of change, evaluated progress or lack of progress in achieving the Aichi Biodiversity Targets, the Sustainable Development Goals (SDGs), and several environmental conventions, and assessed plausible scenarios and possible pathways. Previous chapters of the present assessment show that, despite progress on various goals and targets and improvements in environmental indicators in many regions, species diversity, ecosystems functions and the contributions they provide to society continue to decline, further reinforcing both environmental and societal problems.

While progress can be made to achieve the Aichi Biodiversity Targets, the CBD 2050 Vision and the SDGs using current policies, practices and technologies, and within current national and international governance structures, these are not enough to address current and projected trends. It has become widely recognized that transformative change is needed to fully realize these ambitions (CBD/SBSTTA/21/5, 12 October 2017; CBD/SBSTTA/21/2, 15 September 2017). In fact, the adoption of the SDG shows that the international community has committed itself to such transformative change: "*We are determined to take the bold and transformative steps which are urgently needed to shift the world on to a sustainable and resilient path*" (UNGA, 2015).

Transformative change can be defined as a fundamental, system-wide reorganization across technological, economic and social factors, including paradigms, goals and values (IPBES, 2018a; IPCC, 2018). Such fundamental, structural change is called for, since current structures often inhibit sustainable development, and actually represent the indirect drivers of biodiversity loss (Díaz *et al.,* 2015) (See Section 6.2. below). Transformative change is thus meant to simultaneously and progressively address these indirect drivers. The character and trajectories of this transformation will be different in different contexts, with challenges and needs differing, among others, in developing and developed countries.

Transformative change is facilitated by innovative governance approaches that incorporate existing approaches such as integrative, inclusive, informed and adaptive governance. While such approaches have been extensively practiced and studied separately, it is increasingly recognized that together they can contribute to transformative change (see section 6.2). The concept of governance refers to the formal and informal (and public and private) rules, rule-making systems, and actor-networks at all levels of human society (from local to global) that are set up to steer societies towards positive outcomes and away from harmful ones (adapted from Biermann *et al.,* 2010).

In response to the interconnected challenges of sustainable development, biodiversity conservation,

Table 6 2 **List of decision makers.**

	Decision maker
1	Global and regional (inter)governmental organizations (UN, MEA secretariats etc.)
2	National, sub-national and local governments
3	Private sector
4	Civil society, including: • Citizens (households, consumers), community groups, farmers • NGOs (e.g., environmental, human development, consumer, trade unions)
5	Indigenous Peoples and Local Communities (IPLCs)
6	Donor agencies (public and private)
7	Science and educational organizations

and climate change identified in previous chapters, this chapter organizes its analysis on the options for decision makers around sustainability pathways in five domains: terrestrial landscapes (6.3.2), marine, coastal and fisheries (6.3.3); freshwater (6.3.4); cities (6.3.5); and energy and infrastructure (6.3.6). Finally, the chapter discusses approaches and conditions that enable transformation towards sustainable economies (6.4). Each of these major issues is considered in terms of short- and long-term options, and against possible obstacles for decision makers to enable transformative change. The chapter distinguishes different decision makers (see **Table 6.2**).

Our analysis of options implemented so far shows that, already in the short-term (before 2030), all decision makers can contribute to the transformation towards sustainability by applying existing policy instruments, which need to be enhanced and used together strategically in order to become transformative – in other words – not only address direct drivers, but especially indirect drivers. The existing instruments discussed in sections 6.3 and 6.4 can thus be further enhanced based on the lessons learned from earlier experiences with implementation. In the long-term (today-2050), transformative change will entail additional measures and governance approaches to change technological, economic, and social structures within and across nations.

Below, the chapter first discusses transformative change and transformative governance (section 6.2), after which the options for decision makers on the main issues are discussed (section 6.3). Section 6.4 highlights more generic options for a sustainable economy. The options in sections 6.3 and 6.4 are based on a systematic literature review of existing and emerging governance instruments and approaches. The review especially highlights lessons relevant to transformative governance, including cross-sectoral approaches and synergies and trade-offs between different societal goals, the impact of telecoupling of distant drivers, and lessons learned from incorporating diverse values, rights-based approaches and equity concerns in decision making and policy implementation (see section 6.2).

Due to the scope of the chapter's coverage and the extent of the literature review supporting it, the chapter includes a Supplementary Material document. A significant amount of the literature evidence supporting statements made in the chapter are presented there, thus we encourage the reader to consult Supplementary Material when cross-references are made in the main chapter.

6.2 TOWARDS TRANSFORMATIVE GOVERNANCE

As introduced in 6.1, transformative change can be defined as societal change in terms of technological, economic and social structures. It includes both personal and social transformation (Otsuki, 2015), and includes shifts in values and beliefs, and patterns of social behaviour (Chaffin *et al.,* 2016).

Transformative change has emerged in the policy discourse and is increasingly seen as both necessary and inevitable for biodiversity-related issues and sustainable development more broadly. The Convention on Biodiversity (CBD), European Environment Agency (EEA, 2015), OECD (OECD, 2015), World Bank (Evans & Davies, 2014), UN (UNEP, 2012), UNESCO (ISSC/UNESCO, 2013), European Union, national governments and the German Advisory Council on Global Change (WBGU, 2011), for example, have over the past years launched reports and policy programs in support of sustainability transformations or transitions. This attention is based upon the increasing understanding of the persistency of the complex sustainability challenges we face: in spite of high ambitions, policy commitments, large-scale investments in innovation and voluntary actions, our economies are still developing along unsustainable pathways pushing ecological boundaries (Rockstrom *et al.,* 2009; Future Earth, 2014). To escape this path-dependency it is increasingly clear that structural, systemic change is necessary, and continuing along current trajectories increases the likelihood of disruptions, shocks and undesired systemic change.

This process of nonlinear systemic change in complex societal systems has become the object of research especially since the late 1990s under the headers of 'transformation' (Feola, 2015; Olsson *et al.,* 2014; Folke *et al.,* 2010; Moore *et al.,* 2014) and 'transition' (Geels, 2002; Grin *et al.,* 2010; Markard *et al.,* 2012; Rotmans *et al.,* 2001; van den Bergh *et al.,* 2011; Turnheim *et al.,* 2015). While having different disciplinary origins (Hölscher *et al.,* 2018), both terms are increasingly used in a similar way referring to a particular type of change, namely nonlinear and systemic shifts from one dynamic equilibrium to another (Patterson *et al.,* 2016). A range of different scientific disciplines has studied underlying patterns and mechanisms of such transformation. Prominent fields of research include resilience, sustainability transition, innovation studies and social innovation research. While these debates have often remained rather a-political, a more critical perspective is emerging (see e.g. Blythe *et al.,* 2018; Chaffin *et al.,* 2016; Lawhon & Murphy, 2012; Meadowcroft, 2009; Scoones *et al.,* 2015) that incorporates politics, power, legitimacy and equity issues, recognizing that transformations include the making of "hard choices" by decision makers (Meadowcroft, 2009).

Governing transformative change, or *transformative governance,* can be defined as "an approach to environmental governance that has the capacity to respond to, manage, and trigger regime shifts in coupled socio-ecological systems at multiple scales" (Chaffin *et al.,* 2016). Transformative governance is deliberate (Chaffin *et al.,* 2016), and inherently political (Blythe *et al.,* 2018), since the desired direction of the transformation is negotiated and contested, and power relations will change because of the transformation (Chaffin *et al.,* 2016). Current vested interests (including in certain technologies) are thus expected to inhibit, challenge, slow down or downsize transformative change, among others through "lock-ins" (see e.g., Blythe *et al.,* 2018; Chaffin *et al.,* 2016; Meadowcroft, 2009). The debate on the related term "transition management" (Rotmans & Loorbach, 2010) points to the importance of (facilitating) emergent and co-evolutionary changes in cultures, structures and practices that challenge incumbent 'regimes' (Frantzeskaki *et al.,* 2017). This in itself requires forms of governance that complement more institutionalized, consensus-based and incremental policies by facilitating transformative actor-networks, back-casting processes, strategic experimentation and reflexive learning.

Transformative governance often needs a 'policy' or 'governance' mix aimed at navigating transformations (Kivimaa & Kern, 2016; Loorbach, 2014; Berkes *et al.,* 2008). In such a mix, instruments that facilitate the build-up of alternatives, the gradual change of institutional structures and the managed phase-out of undesirable elements need to be combined, dynamically based on a systemic understanding of the present transition dynamics (Loorbach *et al.,* 2017). How this is operationalized depends on the type of organization and level of operation and the types of (transformative) capacities, instruments and methods available (Wolfram, 2017; Fischer & Newig, 2016; Patterson *et al.,* 2016). Through co-creative multi-actor processes (Avelino & Wittmayer, 2015; Brown *et al.,* 2013) of seeking joint understandings of collective transition contexts and formulating shared desired future directions, different actors can align long-term agendas and more strategically use and implement short-term actions to guide and direct emerging transitions towards sustainable futures.

Transformative change thus needs innovative approaches to governance. Such transformative governance can incorporate different existing approaches, which we group into four domains, namely integrative, inclusive, informed and adaptive governance. While these approaches have been extensively practiced and studied separately, their combined contribution to enabling transformative change has not yet been thoroughly explored.

Transformative governance is: 1) *integrative,* since the change is related to and influenced by changes elsewhere (at other scales, locations, on other issues) (see e.g., Chaffin *et al.,* 2016; Karki, 2017; Reyers *et al.,* 2018; Wagner & Wilhelmer, 2017); 2) *informed*, based on different and credible knowledge systems (Blythe *et al.,* 2018; Chaffin *et al.,* 2016; Couvet & Prevot, 2015); 3) *adaptive,* based on learning, experimentation, reflexivity, monitoring and feedback (Colloff *et al.,* 2017; Chaffin *et al.,* 2016; Laakso *et al.,* 2017; Meadowcroft, 2009; Otsuki, 2015; Rijke *et al.,* 2013; Wagner & Wilhelmer, 2017); and finally 4) *inclusive* since transformative change per definition includes different types of actors, interests and values, and needs to address issues of social justice (Chaffin *et al.,* 2016; Otsuki, 2015; Blythe *et al.,* 2018; Li & Kampmann, 2017; Meadowcroft, 2009; Thomalla *et al.,* 2018; Wolfram, 2016). Below we elaborate on each of these four approaches to governance (not presented in order of importance).

6.2.1 Integrative governance: ensuring policy coherence and effectiveness

Since the middle of the 20th century, hundreds of multilateral environmental agreements, governmental policies and (public-) private initiatives have been developed, many of which are focused on, or relevant for, biodiversity. Moreover, different economic and policy sectors (including biodiversity conservation, climate change, agriculture, and mining) are often governed in silos at all levels of governance. This raises questions per level of governance and across levels of governance on *synergies and trade-offs* between different societal goals (see e.g., Mauerhofer & Essl, 2018). This is especially important for transformative change – the SDG cannot all be achieved simultaneously if they are not approached in an integrative manner – as recognized by the UN, which have stated that the goals and their targets are "integrated in indivisible" (UNGA, 2015).

This fragmentation and complexity of the governance for sustainable development are well recognized among scholars (see e.g., Alter & Meunier, 2009; Bogdanor, 2005; Rayner *et al.,* 2010; Tamanaha, 2008; Young, 1996), and policy makers are actively trying to enhance synergies and address trade-offs. The CBD, for example, promotes mainstreaming of biodiversity concerns into sectors impacting biodiversity, such as agriculture, forestry, fisheries, and tourism (UNEP/CBD/COP/13/24).

Integrative governance defined and the theories and practices focused on the relationships between governance instruments or systems (Visseren-Hamakers, 2015; 2018), addresses these challenges of incoherence in sustainability governance. The literature suggests various options for integrative governance, including:

- Integrated management (Born & Sonzogni, 1995), landscape governance and approaches (Buizer *et al.*, 2015; Görg, 2007; Sayer *et al.*, 2013), the nexus approach (Benson *et al.*, 2015; Rasul & Sharma, 2016), multilevel governance (Hooghe & Marks, 2003; Marks *et al.*, 1996), and telecoupling (Liu *et al.*, 2013), which bring together (or highlight the relationships between) different sectors, policies or levels of governance in trying to enhance coherence;

- (Environmental) policy integration (Jordan & Lenschow, 2010; Persson & Runhaar, 2018) and mainstreaming (Karlsson-Vinkhuyzen *et al.*, 2017; Kok and de Coninck, 2007), which aim to strengthen attention for environmental issues in other sectors;

- Interaction management (Oberthür, 2016), metagovernance, and orchestration (Abbott & Snidal, 2010; Kooiman & Jentoft, 2009), which aim to improve the relationships between (groups of) governance instruments; and

- Smart regulation and policy mixes (Gunningham and Grabosky, 1998; Mees *et al.*, 2014), which combine different instruments to be more effective together.

Additional concepts used to discuss and study integrative governance include interorganizational relations (see e.g., Schmidt & Kochan, 1977), legal pluralism (Griffiths 1986; Merry, 1988), polycentric governance (Ostrom, 2010), regime complexity and fragmentation (Biermann *et al.,* 2009; Fischer-Lescano & Teubner, 2003), coordination (Peters, 1998), coherence (Jones, 2002), institutional interplay or interaction (Oberthür and Gehring, 2006), governance architectures and systems (Biermann *et al.,* 2009), regime complexes (Abbott, 2012; Raustiala & Victor, 2004), and governance of complex systems (Young, 2017) (see Visseren-Hamakers, 2015, 2018). See **Box 6.1** for an example of Integrative Governance.

6.2.2 Informed governance: based on legitimate and credible knowledge

Traditionally, biodiversity governance has relied on natural science tools including red lists, monitoring and indicator frameworks, and models and scenarios to characterize, assess and project ecological values such as productivity, species diversity, or threatenedness. In addition, multidisciplinary tools containing knowledge and information about ecosystems, social systems, and economics, such as cost-benefit analysis, sustainability indicators, or integrated assessments are widely used and considered valuable for their ability to offer an integrated perspective (Ness *et al.,* 2007). Increasingly, these information tools and systems focus on the measurement, modeling and assessment of natural capital and ecosystem services (Turnhout *et al.,* 2013; McElwee, 2017).

These information tools and systems have several challenges and limitations. These include technical challenges such as standardization, data quality and availability, and interoperability and commensurability of data (Bohringer & Jochem, 2007; Kumar Singh *et al.,* 2009). More important is that they are mostly not fit for purpose to inform transformative governance. One reason is that they often focus exclusively on environmental dimensions and are insufficiently inclusive of diverse values (Turnhout *et al.,* 2013; 2018; Gupta *et al.,* 2012; Elgert, 2010). For example, biodiversity and ecosystem services models and assessments often use causal and mechanistic frameworks, such as the DPSIR (Drivers, Pressures, States, Impacts, Responses) approach, which are limited in their ability to account for both complex

Box 6 1 **Example of Integrative Governance – CCAMLR.**

The Commission on the Conservation of Antarctic Marine Living Resources (CCAMLR) manages the currently active fisheries in the Antarctic Treaty System area (Patagonian toothfish (Dissostichus eleginoides), Antarctic toothfish (Dissostichus mawsoni), mackerel icefish (Champsocephalus gunnari) and Antarctic krill (Euphausia superba)). The commission exemplifies integrative governance since it uses a precautionary ecosystem-based approach that considers not just the commercial fish species but also the wider ecosystem, and because its management objectives balance conservation goals with the rational use of living resources, while safeguarding ecological relationships. It does so by using clear decision rules to agree on catch limits in each fishery. It also relies on detailed data from the fisheries and fishery surveys, and the CCAMLR Scheme of International Scientific Observation (https://www.ccamlr.org/en/science/ccamlr-scheme-international-scientific-observation) to monitor CCAMLR fisheries and to forecast fishery closures. Members implement compliance systems that include vessel licensing, satellite monitoring of vessel movements and transshipments, together with measures to specifically address the threat of illegal, unregulated and unreported (IUU) fishing. The CCAMLR conservation measures are generally seen to be efficiently implemented and represent a leading example of an agreement between over 50 States that has been effective in conserving the living resources of a significant part of the world's ocean.

causal pathways and societal factors such as institutions and values affecting them (Svarstadt *et al.,* 2008; Breslow, 2015). Equally, the usefulness of indicator and monitoring systems is hindered by their technical and specialized nature and by the way in which they prioritize specific values over others (Turnhout, 2009; Merry, 2011).

Transformative governance calls for expanding existing information systems and tools to include indicators and parameters to assess the integrative, informed, adaptive and inclusive nature of governance processes, policies and interventions as well as their intended and unintended effects on Nature, NCP and GQL. An interesting initiative in this respect is Conservation Evidence, which aims to improve conservation practice by collating, reviewing, assessing and summarizing all available evidence on the effectiveness of conservation interventions (Sutherland *et al.,* 2004, 2014, 2017). It is conceived to be a free, open-access and authoritative resource designed to support informed decisions about how to maintain and restore global biodiversity, thereby combatting the phenomenon of evidence complacency, where evidence is not used in conservation decision-making (Dicks *et al.,* 2014; Cook *et al.,* 2017; Sutherland & Wordley, 2017).

Informing transformative governance also requires reconsideration of the relationship between knowledge and decision-making. Scientific expertise is not in all cases required for effective and legitimate action, and the relationship between knowledge and decision-making is not straightforward or self-evident (Dessai *et al.,* 2009; Kolinjivadi *et al.,* 2017; Wesselink *et al.,* 2013. Dilling and Lemos, 2011, Sutherland *et al.,* 2004; Matzek *et al.,* 2014; Pullin *et al.,* 2014). This means that existing information systems and tools will need to be adapted to produce knowledge that is inclusive of multiple values and forms of scientific and non-scientific knowledge, including indigenous and local knowledge (ILK), and that is credible, legitimate and salient for all relevant stake- and knowledge-holders (Cash *et al.,* 2003; Robertson & Hull, 2001; Mauser *et al.,* 2013; Sterling *et al.,* 2017).

A crucial element in the production of legitimate and credible information is the facilitation of dialogue and learning (Lemos & Moorehouse, 2005; Breslow, 2015; Kok *et al.,* 2017; Peterson *et al.,* 2003; Turnhout *et al.,* 2007; Voinov & Bousquet, 2010). Literature on transdisciplinarity and coproduction offers a variety of tools and methods that can be used by governments, NGOs but also in bottom-up processes, to organize processes of participatory knowledge production that are able to bridge practical, scientific and technical knowledge, as well as ILK (Tengö *et al.,* 2014, 2017; Clark *et al.,* 2016). Experiences with participatory modeling and scenario planning have shown amongst others that participants were better able to grapple with complexity and uncertainty and that scenarios developed on the basis of input from stakeholders were helpful in identifying different interests and facilitated communication between stakeholders and governments (De Bruin *et al.,* 2017; Tress & Tress, 2003; Whyte *et al.,* 2014). Similarly, participatory – or citizen science – approaches involving stakeholders in the selection and monitoring of indicators cannot just contribute to the availability of relevant data, but also to engagement with nature and enhanced decision-making (Fraser *et al.,* 2006; Danielsen *et al.,* 2014). An interesting example has come from the availability of real-time satellite data, which are used by initiatives like Global Forest Watch to support national and sub-national governments, civil society and the private sector to engage in forest monitoring and conservation (FAO, 2015; GFW, 2017; Nepstad *et al.,* 2014; Assunção *et al.,* 2015).

However, the application of these inclusive and participatory approaches so far is limited (Brandt *et al.,* 2013), and their ability to produce positive outcomes for problem solving and stakeholder empowerment depends on the presence of an enabling institutional context (Armitage *et al.,* 2011) which is able to effectively address unequal power relations between stake- and knowledge-holders (Nadasdy, 2003; Dilling & Lemos, 2011).

6.2.3 Adaptive governance: to enable learning

Transformative change is in essence adaptive – it represents a learning process that needs regular opportunities for reflection on to what extent and how progress is being made, the main bottlenecks, and the best ways forward. Adaptive governance is a result of continuously learning about and adjusting responses to uncertainty, social conflicts and complexity in socio-ecological systems (Chaffin *et al.,* 2014; Dietz *et al.,* 2003; Walker *et al.,* 2004; Folke *et al.,* 2005; Folke, 2006; Karpouzoglou *et al.,* 2016).

Adaptive governance includes policy processes that highlight uncertainties, developing and evaluating different hypotheses around a set of outcomes and structuring actions to evaluate these ideas (Berkes *et al.,* 2003; Paul-Wost, 2009). Adaptive governance also focuses on enhancing the resilience of socio-ecological systems by increasing their capacity to adapt, and by recognizing the importance of learning in coping with change and uncertainty (Evans, 2012). Studies on adaptive governance advocate for an experimental approach to governing such as creating institutions that can experiment with different solutions and make adjustments in the process (Holling, 2004).

There are various challenges stated in the literature that can be seen as problematic in engaging with an adaptive governance paradigm. According to Gunderson (1999) these are inflexible social systems, ecological systems that lack resilience, and technological incapacity to design experimental and innovative approaches. Also, the question of scale is essential in adaptive governance mechanisms. The scale for adaptive governance responses needs to be adapted to the social and ecological nature of the problem with sufficient response flexibility within and between political boundaries (Cosens, 2010, 2013; Huitema *et al.,* 2009; Termeer *et al.,* 2010).

Adaptive management, through monitoring and feedback, is widely recognized as a management approach to ensure effective conservation (Walters, 1986). Several studies confirm the benefits of adaptive management and “learning through doing” (Kenward *et al.,* 2011; CBD, 2004; Bern Convention, 2007), and adaptive management has been applied in the ecosystem approach in order to deal with the complex and dynamic nature of ecosystems and the absence of complete knowledge or understanding of their functioning (CBD, 2017). According to Lebel *et al.* (2006), adaptability is determined by two factors: (1) the absolute and relative forms of social, human, natural, manufactured, and financial capital, and (2) the system of institutions and governance. In order to enable a capacity to adapt, it is crucial to build trust and shared understanding between diverse stakeholders to motivate co-learning and adaptation. Accordingly, deliberation and polycentric governance are offered as tools for enabling adaptive governance.

Dietz *et al.* (2003) propose a general list of criteria necessary for adaptive governance: inclusive dialogue between resource users (analytic deliberation); complex, redundant, layered institutions (nesting); mixed institutional types (e.g., market- and state-based); and institutional designs that facilitate experimentation, learning, and preparation for change. See **Box 6.2** for an example of adaptive governance.

6.2.4 Inclusive governance: ensuring equity and participation

Inclusive governance refers to governance approaches through stakeholder engagement, including Indigenous Peoples and Local Communities, in decision-making processes. It is argued that inclusive governance improves the quality of decisions and secures legitimacy for the decisions that are taken. Reform of decision-making processes is also necessary to enhance accountability and legitimacy (Keohane, 2003; Bernstein, 2005; Biermann & Gupta, 2011; Evans, 2012).

Participatory mechanisms that introduce dialogue and negotiation can be used to discover varying and potentially competing values and knowledge systems and identify options for more equitable decisions and implementation of these decisions, and enable learning (see e.g. Innes and Booher, 1999). However, power asymmetries can also affect the manners in which values and knowledge systems are represented in such participatory platforms. Policymaking processes have often inadequately addressed minority groups or the interests and values of people who are actually or potentially affected, directly or indirectly. Procedural equity deals with power asymmetries that affect whose voice is heard and who has a say in access and control of nature (McDermott *et al.,* 2013).

Deliberative processes are widely recognized by practitioners as useful in many contexts, including urban planning, healthcare and water governance (Andersson & Ostrom, 2008; Neef, 2009; Parkins & Mitchell, 2005). Deliberative approaches are based on the assumption that competing interests and values can only be discovered, constructed and reflected in a dialogue with others (Rhodes, 1997; Dryzek, 2000; Kenter, 2016). Examples of deliberative institutions are citizen juries, consensus conferences and focus groups (Pelletier *et al.,* 1999; Smith, 2003; Lienhoop, 2015). Deliberative approaches are mostly applied at the local level but can also be used at other levels of governance Deliberative valuation can also capture the interests of future generations (Soma & Vatn, 2010; Stagl, 2006; Sagoff, 1998).

Deliberation is considered to be an integrating and bridging approach to valuation (Pascual *et al.,* 2017). Howarth and Wilson (2006) also describe the ways in which deliberative monetary valuation could contribute to social fairness. However, after deliberation it will nevertheless be essential that results be articulated in a metric that is comparable with conventional ecosystem service valuation techniques such as the contingent valuation method (Wilson & Howarth, 2002).

Box 6 2 **Example of Adaptive Governance – Urban green spaces and urban agriculture:**

Uses of vacant lots in urban areas are increasingly recognized as important sites for enhancing provisioning of nature’s contributions, such as water provisioning or climate regulation, and can also be used for food provisioning through urban agriculture. Adaptive governance principles have been realized in several “land bank” systems in the USA, such as in Cleveland, which join public and private organizations to purchase or reclaim parcels and then manage them adaptively for multiple objectives. Such strategies include plans to increase connectivity between lots and incorporate community involvement in lot management (Green *et al.,* 2016).

Inclusive governance to enhance transformative change thus needs to consider the importance of including diverse value systems, rights-holders, genders and IPLCs. These are discussed in more detail below (see **Box. 6.3** for an example of inclusive governance).

6.2.4.1 Value Systems

Decisions – made at the individual or institutional level and at different scales – are necessarily embedded in a given value system, historically rooted in the socio-cultural context and power relations; yet, such value systems may not be explicitly reflected upon (Barton *et al.,* 2018; Berbés-Blázquez *et al.,* 2016). Depending on whether a unidimensional or a more diverse (value pluralism) lens is applied by the decision maker, policy objectives, as well as policy instruments will be determined differently through formal and informal institutions (Pascual *et al.,* 2017; also see Chapter 1). Legal, economic and socio-cultural instruments currently regulating the use of nature and its contributions usually fail to address plural and multiple values of nature, instead they focus on unidimensional values (Chan *et al.,* 2016; Kolinjivadi *et al.,* 2017; Tallis *et al.,* 2014; Spangenberg & Settele, 2016) (See Supplementary Materials 6.1.1 for a discussion on market-based instruments). Additionally, they often have unintended consequences, such as motivational crowding[1] (Rode *et al.,* 2015; Vatn, 2010; Vatn *et al.,* 2014), trade-offs and conflicts (Kovács *et al.,* 2015; Turkelboom *et al.,* 2018, Whittaker *et al.,* 2018), or impacts on justice and power relations (Berbés-Blázquez *et al.,* 2016; Pascual & Howe, 2018; Sikor, 2014). Being transparent about underlying value systems and accommodating plural values and knowledge forms in decision-making widens collaboration and creates more inclusive institutional arrangements (Ainscough *et al.,* 2018; O'Neill & Spash, 2000). However, decision making in this context might be technically challenging (Dendoncker *et al.,* 2018; Phelps *et al.,* 2017; Primmer *et al.,* 2018), because value articulation needs to be equitable; conflicts often emerge between stakeholders holding different values; and plural and incommensurable values are difficult to operationalize in decision making (e.g., include in accounting), among others.

6.2.4.2 Rights-based approaches

Rights-based approaches, at the substantive and procedural level, are multifaceted, and crucial to various aspects of governance including inclusive (e.g., participation rights) and informed (e.g., information rights) governance. In order to promote GQL, national laws and policies integrate the substantive right to a healthy environment, life, water, food, standard of living, and health (Knox, 2013, 2017; Draft Framework Principles on Human Rights and the Environment, 2018). Regional and national laws and policies also integrate procedural rights to information and participation in decision-making (Aarhus Convention, 1998; *Escazú Agreement, 2018;* Knox, 2013, 2017).

In addition, strong *land and sea rights*, including ownership and use rights, can promote local empowerment, reduce tensions between the authorities and resource users, and can be successfully integrated in community management of forests, use of non-timber forest products, communal grazing lands and subsistence fisheries (Oxfam *et al.,* 2016; FAO, 2012; Ring *et al.,* 2018; Acosta *et al.,* 2018; Stringer *et al.,* 2018). Granting land and sea rights to IPLCs is also a critical means for connecting IPLCs with environmental protection policies, including economic instruments such as carbon offsets, REDD+, PES and micro-credits (Gray *et al.,* 2008; de Koning *et al.,* 2011; van Dam, 2011; McElwee, 2012; Larson *et al.,* 2013; Duchelle *et al.,* 2014; Sunderlin *et al.,* 2014). As for *customary rights*, examples confirm that if competing interests between state and customary systems are adequately balanced, policy measures incorporating customary rights are likely to protect traditional values and ILK, respect local power structures and institutions of IPLCs, and contribute to biodiversity conservation (Acosta *et al.,* 2018; Willemen *et al.,* 2018). *Animal rights* are an example of non-anthropocentric development that recognizes intrinsic values of animals and the (ecological) interdependence of humans and animals (Birnie *et al.,* 2009; Kymlicka & Donaldson, 2011). *Rights of Nature* refers to the entitlement of nature with rights as a collective subject of interest, acknowledging its intrinsic values (Rühs & Jones, 2016; Gordon, 2017; Kotzé & Calzadilla, 2017; Rogers & Maloney, 2017). Policy options for the recognition of such rights often imply the articulation of a co-management regime (e.g., Whanganui River, New Zealand; Strack, 2017), and have been codified in national constitutions (e.g., Ecuador; Kauffman & Martin, 2017), national legislation (e.g., Bolivian Law of Mother Earth; Pacheco, 2014) and in local policies (e.g., United States; Sheehan, 2015). Also see Supplementary Materials section 6.1.2.

6.2.4.3 Gender

Gender literacy, women's empowerment, financial support, gender responsive approaches and integrating gender into nature conservation solutions are crucial to reinforce links between gender and biodiversity, achieve biodiversity objectives, and SDG 5 (gender equality) (CBD SBI/2/2 Add.3 (2018); IUCN, 2017). Lack of gender sensitive funding mechanisms and structural inequality hinder gender mainstreaming at the national and local level (Sweetman, 2015; UNEP, 2016). While *gender rights* acknowledge the interdependence between gender, biodiversity conservation

1. Motivational crowding means that the intended motivational impact of an incentive interacts and often changes the internal / intrinsic motivations of actors. Crowding-in means that an external incentive strenghtens intrinsic motivations, while crowding-out means that the incentive decreases intrinsic motivations to protect biodiversity (Rode *et al.,* 2015; Vatn *et al.*, 2014).

and sustainable use of resources (CBD Gender Plan of Action, 2008; Aichi Target 14, 17 and 20), poverty, religious and cultural practices (e.g., when gender disparities are entrenched in cultural and religious beliefs), and unequal social, economic and institutional structures are some of the key obstacles women encounter (CBD/IUCN, 2008; FAO, 2013; UNEP, 2016). The fundamental role women play in, among others, agriculture, forestry, fisheries, tourism, water management, wildlife management, and nature conservation and management underpin the need for effective participation in decision-making (Jenkins, 2017; Howard, 2015). To mainstream gender considerations, governments can take actions in policy (e.g., mainstream gender into NBSAPs), organizational (e.g., giving women collective and individual voice, gender equality training and awareness-raising among decision makers, and gender responsive budgets), delivery (e.g., participatory mechanisms, capacity development and empowerment to enable effective participation), and constituency (e.g., ensure consistency with relevant conventions) spheres (CBD Decision XII/7 (2014).

6.2.4.4 IPLCs and ILK

Inclusive governance requires robust participatory mechanisms supporting the inclusion of IPLCs in policies and planning decision affecting them and the environment at large (Bray *et al.,* 2008, 2012; Ojha *et al.,* 2009; Kerekes & Williamson, 2010; Kothari *et al.,* 2012, 2013; Mooney & Tan, 2012; Buntaine *et al.,* 2015). As discussed in chapter 2, IPLCs hold territorial rights and/or manage a substantial proportion of the world's conserved nature, freshwater systems, and coastal zones, providing contributions to society at large (Maffi, 2005; Gorenflo *et al.,* 2012; Renwick *et al.,* 2017; Garnett *et al.,* 2018). There is well-established evidence that IPLCs can develop complex, sophisticated, innovative and robust institutional arrangements and management systems for successfully governing the management of watersheds, coastal fisheries, forests and grasslands and a variety of biodiversity-rich landscapes around the world (Ostrom, 1990; Berkes, 1999; Agrawal, 2001; Colding & Folke, 2001; Lu, 2001; Toledo, 2001; Gadgil *et al.,* 2003; Bodin & Crona, 2008; Pacheco, 2008; Waylen *et al.,* 2010; Basurto *et al.,* 2013; Stevens *et al.,* 2014; Fernández-Llamazares *et al.,* 2016) to govern their land- and seascapes in ways that align with biodiversity conservation (ICC, 2008, 2010; Stevens *et al.,* 2014; Ens *et al.,* 2015, 2016; Trauernicht *et al.,* 2015; Blackman *et al.,* 2017; Schleicher *et al.,* 2017; Vierros, 2017).

The inclusion of IPLCs in governance can be enhanced through processes of knowledge coproduction at local, national and global scales (Brondizio & Le Tourneau, 2015; Sterling *et al.,* 2017; Wehi & Lord, 2017, Turnhout *et al.,* 2012; Tengö *et al.,* 2014, 2017; FPP & CBD, 2016; see also 6.2.2 and Chapter 1). Such enhanced participation has been shown to improve dialogue and advance the legitimacy of decisions and the recognition of the value and rights of IPLCs (Schroeder, 2010; Redpath *et al.,* 2013; Brugnach *et al.,* 2014; Wallbott, 2014, Brodt, 1999; Young & Lipton, 2006; Berkes, 2009; Davies *et al.,* 2013; Robinson *et al.,* 2014; Stevens *et al.,* 2014; Gavin *et al.,* 2015; Alexander *et al.,* 2016; Berdej & Armitage, 2016, Ostrom, 1990; Gibson *et al.,* 2005; Hayes, 2006, 2010; Chhatre & Agrawal, 2008, 2009; Waylen *et al.,* 2010; Porter-Bolland *et al.,* 2012; Reyes-García *et al.,* 2012; Gavin *et al.,* 2015; Martin *et al.,* 2016). However, long-term capacity development, empowerment and continued funding support are critical conditions to ensure IPLCs involvement in biodiversity conservation, including specifically women, youth and non-Indigenous communities (Brooks *et al.,* 2009; Ricketts *et al.,* 2010; Eallin, 2015; Escott *et al.,* 2015; Reid *et al.,* 2016; Reo *et al.,* 2017).

There are many tools available to set up such inclusive and participatory mechanisms (Green *et al.,* 2015; Pert *et al.,* 2015; Brondizio & Le Tourneau, 2016; Schreckenberg *et al.,* 2016; Fernández-Llamazares & Cabeza, 2017; Zafra-Calvo *et al.,* 2017), including IPLC-led codes of ethical conduct in conservation (e.g., Akwe: Kon Guidelines and The Tkarihwaié:ri Code of Ethical Conduct; CBD, 2004, 2011), the Free, Prior and Informed Consent principle (Cariño, 2005; Doyle, 2015; Herrmann & Martin, 2016; MacInnes *et al.,* 2017; UNDRIP, 2007), and tools for dialogue such as the Whakatane Mechanism (Freudenthal *et al.,* 2012; Sayer *et al.,* 2017), as well as legal approaches that draw inspiration from ILK and customary institutions (Archer, 2013; Hutchinson, 2014; Akchurin, 2015; Humphreys, 2015; Strack, 2017; also see rights-based approaches above). In this vein, the laws promoting the Rights of Nature (e.g., Bolivia, Ecuador, India, New Zealand) have been, in most cases, heavily influenced by IPLC philosophies placing nature at the center of all life (Akchurin, 2015; Díaz *et al.,* 2015; Borràs, 2016; Archer, 2013; Hutchinson, 2014; Strack, 2017; Kothari & Bajpai, 2017). Moreover, securing connection to place and granting land- and sea tenure rights to IPLCs are also a critical means to ensure IPLC participation in environmental governance and key enabling factors to IPLCs' well-being (Gray *et al.,* 2008; de Koning *et al.,* 2011; van Dam, 2011; McElwee, 2012; Larson *et al.,* 2013; Sunderlin *et al.,* 2014; Sterling *et al.,* 2017). Finally, global policy arenas such as IPBES and the CBD can facilitate knowledge co-production for enhanced environmental governance (Turnhout *et al.,* 2012; Tengö *et al.,* 2014, 2017; FPP & CBD, 2016). **Figure 6.1** outlines several public policies that can facilitate IPLC inclusion in transformative governance. Also see Supplementary Materials section 6.1.3 for background material on IPLCs and ILK, and **Box 6.3** for an example of inclusive governance.

Box 6 3 Example of Inclusive Governance – The Arctic Council.

The interconnected and complex challenges faced by the Arctic have been argued to be better addressed through transformative governance, including stronger transboundary cooperation and globally-coordinated policy responses (Aksenov *et al.,* 2014; Chapin *et al.,* 2015; Sommerkorn & Nilsson, 2015; Nilsson & Koivurova, 2016; Armitage *et al.,* 2017; Edwards & Evans, 2017; van Pelt *et al.,* 2017; Burgass *et al.,* 2018). As one of the fastest changing regions on Earth (ACIA, 2004; Wassmann *et al.,* 2011; Cowtan & Way, 2014), the Arctic is facing vast social-ecological challenges that have required all levels of governance –particularly the Arctic Council– to constantly adjust their modes of operation, ensuring a governance system that is transformative, flexible across issues and sectors, and adaptable over time (Axworthy *et al.,* 2012; Young, 2012; Chapin *et al.,* 2015; Ford *et al.,* 2015). The Arctic Council (AC), established in 1996, is an intergovernmental forum promoting cooperation, coordination and interaction among the Arctic States, Arctic Indigenous communities and other Arctic inhabitants on common Arctic issues, with an overall focus on encouraging transformative change towards sustainability (Young, 2012; Bloom, 1999; Axworthy *et al.,* 2012; Nilsson & Meek, 2016). Inclusiveness is an important principle for the AC and is best reflected by the unique formal status accorded to Arctic Indigenous Peoples as Permanent Participants, sitting at the table alongside State representatives (Bloom, 1999; Young, 2005). The AC has advanced the inclusion of Indigenous knowledge and expertise in AC assessment reports by placing Indigenous representatives in the steering committees of the different constituencies, task forces and working groups of AC (Kankaanpää & Young,2012) and has catalyzed Indigenous Peoples' participation in international policymaking more generally (Koivurova & Heinamäki, 2006). The AC has however also been criticized for continuing to rely on fixed governance fundaments (e.g., soft law nature, ad-hoc funding; Koivurova, 2009) and for failing to offer the kinds of firm institutional, financial and regulatory frameworks that are considered necessary (Berkman & Young, 2006; Greenpeace, 2014; Hussey *et al.,* 2016; Edwards & Evans, 2017; Harris *et al.,* 2018). (See for more details Supplementary Materials section 6.1.4).

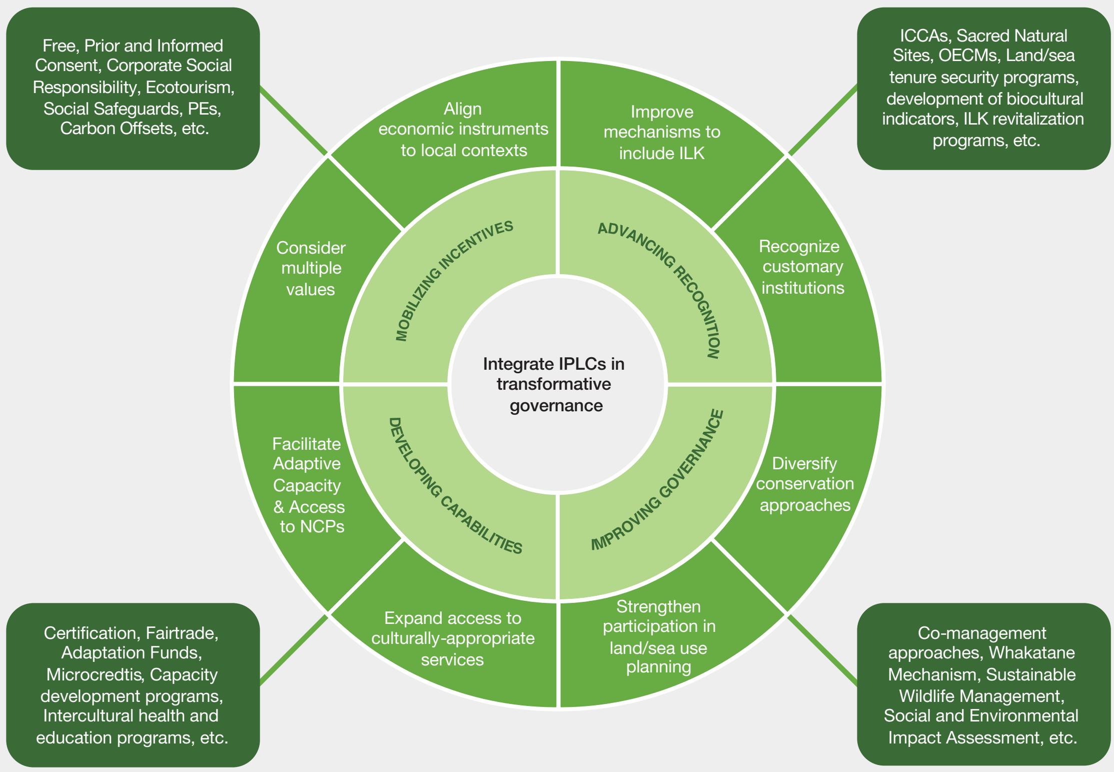

Figure 6 1 **Suite of policy opportunities and actions to better integrate Indigenous Peoples and Local Communities in transformative governance for sustainability.**

Design adapted from Strassburg *et al.* (2017).

6.3 TRANSFORMATIVE CHANGE IN AND ACROSS ISSUES, GOALS AND SECTORS

6.3.1 Introduction

As discussed in the above, the SDG are integrated and indivisible. Therefore, action on one SDG may (positively or negatively) affect progress on other SDG, and the implementation of different targets under an SDG are mutually dependent. Moreover, biodiversity is at the core of many of these complex interdependencies. To the global North and South, the comprehensive implementation of the goals offers major and different challenges to achieve sustainability in the environmental, social, and economic spheres.

Furthermore, as previous chapters have discussed, climate change is exacerbating and reinforcing other drivers of biodiversity loss and environmental degradation, such as habitat loss and degradation, agricultural expansion, unsustainable utilization, invasive alien species and pollution (particularly in marine and freshwater ecosystems; see Chapter 2.1). Various manifestations of climate change such as drought, extreme weather fluctuations, flooding, extreme heat and cold, storms, conditions for accidental fire, ocean water warming and acidification, and rising sea levels, are hindering our ability to meet the Aichi Biodiversity Targets and the SDG.

In this context, the aim of this section is to review both short-term (today-2030) and long-term (today-2050) options available to different decision makers **(Table 6.2)** to achieve the SDG on major biodiversity-related issues and policy domains, including terrestrial landscapes (6.3.2); marine, coastal and fisheries (6.3.3); freshwater (6.3.4); cities (6.3.5); and energy, mining and infrastructure (6.3.6). The overview table in each section summarizes the options that policy makers can include in policy mixes to together address the indirect drivers. The tables include the short- and long-term options, the main problems expected in their implementation, the main decision maker(s) involved, the main levels of governance involved (from the global to the local), and the main targeted indirect driver(s). Some of the common threads emerging from the synthesis below are the following:

First, integrated approaches within an SDG (various targets within one SDG) or among SDG (e.g., the water-food-energy-infrastructure nexus) offer opportunities to foster policy coherence, minimize unforeseen externalities and reduce potential conflict or tensions between different objectives or policies. Promising interventions include practicing integrated water resource management and landscape planning across scales, integrated coastal management, and bioregional scales for energy etc. In addition, policy mixes play a crucial role to address externalities and incorporate diverse values.

Second, data gathering, monitoring and reporting enable decision makers to understand the function and inter-related dynamics of nature, its contributions, and quality of life. Different types of assessment and analytical tools (e.g., cost benefit analysis, life cycle analysis, environmental impact assessment, strategic impact assessment, and participatory assessment) synthesize different types of knowledge, including indigenous and local knowledge. In addition, telecoupled information flows have the potential to contribute to monitoring, surveillance and control. Examples of these options are zero-deforestation pledges, certification schemes for key commodities or biofuel, and the use of satellite surveillance of at-sea fishing operations.

Third, collaborative efforts such as partnerships and other multi-stakeholder approaches among state, market and civil society actors can contribute towards achieving sustainability on all major issues discussed here. In addition, the development of robust, evidence-based, participatory and inclusive decision-making processes optimizes the participation of IPLCs and marginalized social groups (e.g., urban slum dwellers) in environmental governance. Enhanced participation and leadership of IPLCs in environmental processes can advance the recognition of the social, spiritual and customary values of IPLCs in environmental management decisions and influence the outcome, thereby enhancing their legitimacy.

Fourth, it is acknowledged that the effectiveness of policy instruments is context specific, and the implementation of different policy options needs to be adaptive. Moreover, the effectiveness of various policy instruments is not yet well understood and further research on the effectiveness of different policy options, separately and in combination, is necessary to achieve transformative change.

6.3.2 Integrated Approaches for Sustainable Landscapes

Landscapes are the geographical space where socio-ecological systems are shaped and develop. They are the most important source of food, water, materials and bio-energy, and provide space and quality for human habitation. Hence, landscapes are also the space where multiple land uses and values converge. Historically, landscapes have been governed by policies and decisions from different sectors and governance levels, i.e. agriculture, rural development, water, forestry, infrastructure, energy and urban planning, acting often independently without taking due consideration of the interdependencies and trade-offs among different societal objectives that often arise in landscapes.

The lack of articulation of these multiple objectives has been the cause of the large environmental, health and biodiversity loss challenges today, including the conversion and fragmentation of species habitats, one of, and in some regions the main driver of global biodiversity loss (Barnosky *et al.,* 2011; Ceballos *et al.,* 2015; Pimm *et al.,* 2014, Chapter 3 section 3.2.1), the levels of mechanization and resource inputs leading to landscape and biological homogenization (Newbold *et al.,* 2015; Pepper *et al.,* 2017), the lack of adequate attention for the protection of genetic resources of crops, trees, their wild relatives, and livestock (Collette *et al.,* 2015), the skewed representation of biodiversity in protected areas (Butchard *et al.,* 2012, 2015), and the loss of the capacity of soils, cropland and forested areas to maintain ecosystem services (Vitousek *et al.,* 1997; Schiefer *et al.,* 2016, Fornara *et al.,* 2008), including natural pest control and pollination. These challenges are associated with depletion, eutrophication and pollution of water, health problems related to undernourishment and simplified diets (United Nations, 2015), increased costs and risks in food and forestry production due to the introduction of invasive alien species (IAS), and the contribution of landscapes to greenhouse gas (GHG) emissions (FAO & ITPS, 2015, Supplementary Materials 6.2.1).

One unresolved question is how to shape landscapes that fulfil current and future needs of food and materials production, without the negative impacts on nature and society listed above. "Land-sparing" and "land-sharing" represent two extreme models about how landscapes can be shaped and refer to the degree of compatibility between different land use intensities, the conservation of biodiversity and generation of ecosystem services within a landscape (Balmford *et al.,* 2005; Fischer *et al.,* 2008; Phalan *et al.,* 2011, 2016, see also Supplementary Materials 6.2.1). This simplified dichotomy ("land sparing" vs. "land sharing") limits future possibilities (Chapter 5 section 5.3.2.1). There is increasing consensus in that visions of sustainable land-use systems will lie in between these contrasting models, by considering the specific social, economic, ecological and technological context (Fischer *et al.,* 2008; Tscharntke *et al.,* 2012; Chapter 5 section 5.3.2.1). A landscape-focused participatory approach to policy design and implementation is an option to better address dilemmas about land use allocation and intensity of use.

This section analyses the evidence on the effectiveness of policy options that could be used by different decision makers to promote the transition to sustainable landscapes. To contribute to transformative change, options for sustainable agriculture and forest management and conservation would need to be approached with policy mixes (as discussed in 6.2.1 above on integrative governance): "…a combination of policy instruments that (evolves to) influence the quantity and quality of biodiversity conservation and ecosystem service provision in public and private sectors" (Ring & Schröter-Schlaack, 2011). These mixes can include policy instruments beyond the landscape, for instance to regulate the distance drivers of change (i.e., telecouplings) (see section *Regulating commodity chains,* below), including the effect of distant consumption patterns (see section on *Encouraging dietary transitions and alternate consumption,* below).

A policy mix approach is motivated because even in simple settings, no single policy instrument is superior across all evaluation criteria (including effectiveness, cost-minimization, equity) (Vatn, 2010), and cannot possibly address all policy goals and targets. In contrast, well-integrated and implemented policy mixes can help counteract these and other deficiencies, such as economic externalities occurring with market power, unobservable behaviour and imperfect information; and address multiple jurisdictions and policy linkages across jurisdictions (Barton *et al.,* 2013). Successful policy mixes acknowledge the socio-ecological context (Andersson *et al.,* 2015), address conservation and sustainable use challenges, and recognize their cross-sectoral and multi-scale nature (Verburg *et al.,* 2013). If well planned, policy mixes can also address different objectives across the landscape, such as through a 'policy scape' perspective. A 'policy scape', understood as the spatial configuration of a policy mix (Barton *et al.,* 2013; Ezzine-de Blas *et al.,* 2016), recognizes the spatial variation of ecological and biodiversity features, suitability for sustainable food and materials production, and trade-offs between sustainable production and conservation (Schröder *et al.,* 2014; 2017).

Transformative landscape governance networks can further develop policy mixes that integrate across sectors, land uses, actors and levels of governance (Carrasco *et al.,* 2014), addressing important trade-offs among NCP in a transparent and equitable way. Options in the short and longer-term incorporate decision makers and stakeholders from within and outside the landscape while addressing power dynamics (Ishihara *et al.,* 2017; Berbés-Blázquez *et al.,* 2016). These networks are thus multi-actor (including different types of actors), multi-level (including multiple levels of governance, from the global to the local) (Verburg *et al.,* 2013), and multi-sector (including representatives from different sectors, including the entire value chain, from producer to end user) (Lim *et al.,* 2017). Decision makers and stakeholders in these networks need to recognize different values and be cognizant of power dynamics in the networks in order to enable transformative change. Any type of decision maker could initiate such networks.

The options discussed in the remainder of this section, and summarized in **Table 6.3**, can be potential elements of these policy mixes for integrated landscape approaches. They mainly include existing instruments aimed to support sustainable agriculture, sustainable forest management and biodiversity conservation, and thus represent options that can be implemented in the short term. Water governance, although an integral part of landscapes, is discussed in section 6.3.4. However, it is only when these options are strategically combined in integrated landscape approaches that transformative change towards sustainability can take place. Such approaches can be started in the short term but need to be continuously enhanced through transformative governance in the longer term.

Table 6 3 **Options for integrated approaches for sustainable landscapes.**

Short-term options (incremental and transformative)	Long-term options (in the context of transformative change)	Key obstacles, risks, spill-over, unintended consequences, trade-offs	Major decision maker(s) (see Table 6.2)	Main level(s) of governance	Main targeted indirect driver(s)
Sustainable landscapes					
Harmonized, synergetic, cross-sectoral, multi-level and spatially targeted policy mixes, developed through transformative landscape governance networks		Sectoral policy formulation; limited resources and technical capacity; limited resolution of trade-offs; lack of policies inclusive of the entire market that address leakage and telecoupling	Governments; Science and educational organizations; private sector; civil society, IPLCs	All	Economic; institution; governance
Feeding the world without consuming the planet					
Expanding and enhancing sustainable intensification in agriculture (including crops and livestock)		Limited public investment in innovation and outreach activities; limited research and innovation in production embracing sustainability principles; economic and social inequalities	FAO, OIE, governments; science and educational organizations; civil society; donors	National and sub-national	Technological; economic
Encouraging ecological intensification and sustainable use of multi-functional landscapes		Lack of cross-sectoral policy integration; potential high risk of conflict with conservation; limited spatial/territorial planning; limited capacity to resolve trade-offs; lack of understanding about production benefits from improved biodiverse/multiple-value use of land; limited landholder buy-in; pressure to further intensify ('productivist' agricultural paradigm)	Governments; science and educational organizations; private sector; civil society; donors	National; sub-national and local	Institutions; governance; economic
Improving certification schemes and organic agriculture		Limited demand for certified products; lack of landscape level coverage; risk for leakage; voluntary; tends to prioritize brokers and industries; less participation of poor farmers; requires market integration; standards unclear for consumers	Civil society; private sector; governments	Global; regional; national	Cultural; institutions; economic; governance; technological
Regulating commodity chains		Small-farmer exclusion due to high transaction costs of certification and lack of domestic markets; limited expansion of certified area; risk of limited acknowledgement of local customary rights; lack of effective external control; promotion of segregated landscapes; overlooks root causes of land-use expansion; voluntary standards	Civil society; private sector	Global; regional; national	Institutions; governance; cultural; economic
Conserving genetic resources for agriculture		Lack of integration of local genetic resources networks and global processes; lack of integration of genetic resources in biodiversity conservation; risk of increasing social and economic inequalities; lack of recognition of IPLCs and intellectual property rights; limited trait control and seed quality standards	Global and regional (inter-) governmental organizations; private sector; IPLCs; science and educational organizations	All	Institutions; governance; technological

Short-term options (incremental and transformative)	Long-term options (in the context of transformative change)	Key obstacles, risks, spill-over, unintended consequences, trade-offs	Major decision maker(s) (see Table 6.2)	Main level(s) of governance	Main targeted indirect driver(s)
Managing Large-Scale Land Acquisitions (LSLA)		Risk of leakage effects; social and economic marginalization of local farmers; increased tenure insecurity in surrounding lands	Intergovernmental organizations, private sector; farmers	All	Economic; institutions, governance
Encouraging dietary transitions		Lack of consumer awareness of environmental, health and animal welfare implications of food types; lack of effectiveness of information campaigns; voluntary labeling of products; limited market shares of certified products, labeling often emphasizing documentation not performance; low price of unsustainable food	National, subnational and local governments; private sector; citizens; NGOs, science and education organizations	All	Economic; cultural
Reducing food waste	Transformations in food storage and delivery	Failures in food distribution and storage systems; limited consumer education; wasteful marketing practices; limited recycling of food waste; wasteful supply chains and business models	Private sector; citizens (consumers); national and subnational governments; donors; science and education organizations	National; subnational; local	Institutions; governance; cultural
Improving food distribution and localizing food systems		Disconnect between production, consumption and waste management; poor integration in urban planning; limited connection between producers and consumers	National and subnational governments; private sector; citizens (consumers)	National and subnational	Economic; institutions; governance; technological
Expanding food market transparency and price stability		Opposition to government role in stabilizing food prices and food security; limited social targeting to support poor populations	Intergovernmental organizations; National governments; private sector	National	Governance; economic; institutions
Sustainably managing multi-functional forests					
Expanding and improving community-based forest management and co-management		Bureaucratic (and political) apathy; institutional resistance from forest bureaucracies	Governments; civil society; IPLCs	National; sub-national and local	Institutions; governance; demographic
Improving policies relating to PES and REDD+		Informational and other asymmetries among stakeholders; complexities in benefit sharing; unclear or contested tenure; unfavorable institutional and policy settings; over-prioritization of market incentives; limited range of ecosystem services compensated for; international disagreement; trade-offs and conflicts between carbon and other benefits (including biodiversity conservation); stakeholders not always involved in policy design	Global institutions (UN, MEAs); governments; donor agencies; civil society	All	Governance; institutions; economic; technological
Supporting Reduced Impact Logging (RIL)		Insufficient technical and financial capacity, especially in forest-rich tropical countries	Governments; science & educational organizations, private sector	National; sub-national and local	Technological; economic
Promoting and improving forest certification		Limited technical and financial capacity for forest management; low demand for certified products; lack of information among consumers	Governments; science & educational organizations; private sector; NGOs; donors	All	Economic; institutions; governance; cultural; technological
Controlling illegal logging		Weak local governance, poor level of compliance; difficulties with monitoring and traceability; insufficient reward for legal forest harvests in global timber market; difficulties with monitoring and traceability	Intergovernmental organizations; governments; private sector, donors; civil society	All	Governance; institutions; economic

Short-term options (incremental and transformative)	Long-term options (in the context of transformative change)	Key obstacles, risks, spill-over, unintended consequences, trade-offs	Major decision maker(s) (see Table 6.2)	Main level(s) of governance	Main targeted indirect driver(s)
Monitoring and regulating forest use		Insufficient technical and financial capacities; poor understanding of the needs and benefits; weak local governance; poor level of compliance; difficulties with monitoring and traceability systems	International organizations (e.g. FAO); governments; educational organizations; IPLCs	All	Governance; economic, technological
Protecting nature					
Improving management of protected areas (PAs)		Inadequate resources and weak governance; increased human pressures; climate change; limited enforcement, limited monitoring; lack of robust ecological data to assess effectiveness across spatial & temporal scales	International organizations (e.g. IUCN); governments; NGOs; donors	All	Governance; institutions; technological
	Improving spatial and functional connectivity of PAs	Isolation of PAs; geographical and ecological biases; limited spatial planning; trade-offs among societal objectives	Global organizations; governments; NGOs; donors	All	Governance; institutions; technological
	Improving transboundary PA and landscape governance	PA planning usually depends on individual governments	Global organizations; national governments; NGOs; donors	All	Governance; institutions
Recognizing management by IPLCs and OECMs		History of conflicts between IPLCs and legal PA management; potential displacement, exclusion, distress of IPLCs due to strict PA governance; unequal sharing of costs and benefits between different actors; erosion of ILK	Governments; NGOs; private sector; IPLCs; donors	All	Cultural; governance; institutions; regional conflicts
Addressing the illegal wildlife trade		Poor law enforcement; limited capacity for detection; limited surveillance; corruption; limited capacity of crime investigation	Global institutions (CITES); national governments; citizens; IPLCs; NGOs	All	Governance; cultural; economic
Improving Sustainable Wildlife Management		Lack of recognition of IPLC rights; unequal distribution of benefits; elite capture; leakage effects; lack of enforcement of law and international agreements; corruption	Governments; IPLCs; private sector; NGOs	All	Governance; institutions; economic
Manage IAS through multiple policy instruments		Legal and institutional barriers to effective management; information management challenges; lack of resources; limited perception of risks; jurisdictional issues; lack of coherent systemic and community-partnered approach to IAS management; lack of economic incentives to engage private landowners; limited engagement of IPLCs	Global organizations; governments	All	Governance; institutions; cultural; technology; economic
Expanding ecosystem restoration projects and policies					
Expanding ecosystem restoration projects and policies and link to revitalization of ILK		Uncertainty about effectiveness; limited formal and empirical evaluation of projects; risk for limited acceptance of project (neglect of community culture and values); rapid cultural change	Governments; science and education organizations; private sector; IPLCs	National and local	Technology; economic; cultural
Improving financing for conservation and sustainable development					
Improving financing for conservation and sustainable development		Lack of understanding of what financing mechanisms are most effective; priorities for financing in other sectors above biodiversity; lack of consistent monitoring of ODA for biodiversity	Global organizations; national governments; donors	Global; regional; National	Economic; governance; institutions

6.3.2.1 Feeding the world without consuming the planet

Expanding and enhancing sustainable intensification in agriculture

To address land degradation (IPBES, 2018b) and other environmental impacts of agriculture, two forms of ecological modernization are currently considered: (i) sustainable intensification (Sustainable intensification or efficiency-substitution agriculture (Duru *et al.,* 2015, Schiefer *et al.,* 2016), which aims to improve input use efficiency and minimize environmental impacts. This is currently the dominant modernization alternative (see Supplementary Materials 6.2.2; Chapter 2.3 about trends in production for marketed commodities). (ii) *biodiversity-based agriculture* aims to develop agriculture enhancing ecosystem services generated by agro-diversity (Duru *et al.,* 2015) (see section on "Encouraging sustainable use of multifunctional landscapes", below).

Efficiency-based agriculture consists of adjusting practices in specialized systems to comply with environmental regulations and follows the logic of economy of scale and expression of comparative advantages (e.g., for soil fertility, climate, knowledge, labour costs, infrastructure, and regulations) (Duru *et al.,* 2015), aiming at closing yield gaps (Mueller *et al.,* 2012, Chapter 5 section 5.3.2.1). Implementation is based on good agricultural practices (e.g. FAO), and international voluntary standards, including those on animal health and welfare of the World Organization for Animal Health (OIE), and uses also new technologies such as precision agriculture (Supplementary Materials 6.2.2).

The adoption of these practices can be supported by investment in technological development and outreach, regulations, and public and private quality standards such as voluntary certification schemes and roundtables (see sections on *Improving certification schemes* and *Regulating commodity chains*, below). One recent example of the mixes of measures that can promote this kind of agricultural modernization is the program to encourage the sustainable increase of crop yields in smallholder farms in China. In 2003–11, the country increased its cereal production by about 32% (more than double the world average), largely by improving the performance of the least-efficient farms, through a comprehensive package of measures that included public investment, development and testing of technologies adapted to specific agro-ecological zones that improved yields, conserved soils and reduced fertilizer application, and outreach and farmer engagement (Zhang *et al.,* 2013). Development of new crop varieties remains one of several areas of fundamental research that feed into this approach to increase yields and reduce the use of insecticides (Zhang *et al.,* 2013).

Efficiency agriculture is applied to both crops and livestock production. Industrial production systems produce over two-thirds of global production of poultry meat, almost two-thirds of egg production and more than half of world output of pork, with beef and milk production remaining less intensified (FAO, 2009). The environmental impacts, including water, soil and air pollution, of intensive livestock production are significant, and these systems often harbor poor animal welfare conditions (HLPE, 2016). Challenges of efficiency agriculture, including the industrial production of livestock, generally rely on high levels of anthropogenic inputs and include the extensive use of non-renewable resources such as mineral fertilizers and energy, the risk of pest resistance to agro-chemicals (Duru & Therond, 2014), human health problems associated with the use of pesticides and veterinary drugs, the homogenization of crops, and the biological deterioration of the land. This kind of intensification may trigger land conversion as has been the case of soybean expansion in South America (Fearnside, 2001; Pacheco, 2012). Shortcomings can also involve leakage effects and failure to address the conservation of semi-natural and open habitats (Supplementary Materials 6.2.2), issues due to the shift of agricultural production from small and medium household farms to international agroindustry pools (Strada and Vila 2015), and exposure to market volatility.

Encouraging ecological intensification and sustainable use of multi-functional landscapes

Land-use systems consisting of mosaics of cropland, grasslands and pastures, and forests, are widely spread globally and are critical for food security and sovereignty (Supplementary Materials 6.2.2). Encouraging use of multi-functional landscapes can be the basis for a shift towards *ecological intensification or biodiversity-based agriculture* including diversification of food sources, ecological rotation and agroforestry, promotion of agroecology with a view to promoting sustainable production and improving nutrition (McConnell, 2003). At the same time, these landscapes are the space where the largest conflicts with nature conservation can take place (Ravenelle & Nyhus, 2017), especially in the case of wildlife – human interactions.

Multi-functional landscapes also support NCP critical to IPLC diets and food systems. These are also gaining attention in the context of global discourses around food sovereignty (Patel, 2009) and cultural identity (Charlton, 2016; Coté, 2016; Kuhnlein *et al.,* 2009; Nolan & Pieroni, 2014). Many IPLCs and a wide range of rural and peri-urban populations, remain highly dependent on hunting, fishing and gathering for their diets, which play a critical role in supporting IPLC health and well-being (Kuhnlein, 2014; Kuhnlein & Receveur, 2007; ICC, 2015; Nesbitt & Moore, 2016). As such, drivers of landscape homogenization and biodiversity loss have been largely associated with rapid nutritional shifts among IPLCs, through the reduction in consumption of locally-sourced foods as well as the incorporation of industrially processed products, often leading to increasing rates of overweight, obesity and chronic disease (Popkin, 2004; ICC, 2015; Galvin *et al.,* 2015; Iannotti and Lesorogol, 2014; Reyes-García *et al.,* 2018). Measures to promote multi-functional landscapes are easier to govern when they are broadly defined and linked to values or objectives in the sector or local practices (Runhaar *et al.,* 2017). Community-driven and culturally-appropriate responses to address these changes posit a reconnection of land-based food systems and have recurrently called for supporting the recognition of IPLC food sovereignty (Wittman *et al.,* 2010; Morrison, 2011; Rudolph & McLachlan, 2013; Martens *et al.,* 2016). Also, targeting specific measures by identifying agro-ecological constraints and characteristics of farming systems such as population pressure, urbanization, governance, income and undernourishment, can further help select suitable measures to promote ecological intensification in agriculture (Sietz *et al.,* 2017) and the management of NCP based on biodiversity.

Policy options that have been implemented to promote ecological intensification of farming systems include, although not exclusively, direct payments such as agri-environmental schemes (AES) to conserve and better provision ecosystem services (Supplementary Materials 6.2.2) and to maintain and restore habitats (Montagnini *et al.,* 2004), payments for ecosystem services (PES) to protect water sources (Frickmann Young *et al.,* 2014), with biodiversity conservation as a co-benefit (see section on *Improving REDD+ and PES),* below), and standards and certification schemes (see section on *Improving Certification Schemes and Organic Agriculture*, below). A form of biodiversity-based agriculture is permanent (agri)culture, based on broad principles defined as mimicking ecological patterns, locally designed and recuperation of traditional ecological practices (Roux-Rosier *et al.,* 2018).

Technical assistance and investment (including micro-credits) have been used to promote land uses such as agro-forestry systems that enhance on-farm provisioning (e.g. timber and non-timber products in addition to crops and pastures (Montagnini, 2017, Part III) and regulating services such as carbon sequestration. Direct payments (e.g., PES) can be combined with technical assistance since they are effective in overcoming initial economic and technical obstacles to the adoption of agro-forestry practices (Cole, 2010), but the practices need short to medium-term technical support to ensure their long-term retention. These measures have been combined with REDD+ (see section on REDD+, below) to promote carbon sequestration and halt forest clearing.

Participatory approaches and compensation schemes have helped resolve conflicts between food and material production and nature conservation, including wildlife conservation in these mixed-use systems (see section on *Improving Sustainable Wildlife Management*, below) where multiple objectives converge. Finally, the farmers' level of adoption of practices in voluntary schemes (AES, PES, REDD+, technology adoption and certification schemes) is, in many instances, low and largely determines the effectiveness of the measures (Giomi *et al.,* 2018; Runhaar *et al.,* 2017). Two obstacles related to direct payments, a widely used policy instrument, include its voluntary character and that subsidies often do not cover all costs (Runhaar *et al.,* 2017). Farmers who do not voluntarily engage in nature conservation could be incentivized by showcasing farmers who have made advances, critical consumers, and stricter rules in direct payment schemes or in generic agri-environmental legislation (Giomi *et al.,* 2018). Farmers need to be motivated, able, or enabled (e.g. through investment in technological development and outreach), demanded (through regulations and quality standards as the IFOAM-Organic standard and roundtables (see *Improving Certification Schemes and Organic Agriculture*, below), and legitimized to participate and act (Runhaar *et al.,* 2017). There are also other private forms of governance including the cooperation of farmers with conservation NGOs, or compliance to conservation standards requested by companies in agricultural supply chains as part of their Corporate Social Responsibility programmes (Runhaar *et al.,* 2017).

Improving certification schemes and organic agriculture

Over the last decades, voluntary sustainability standards (VSS) and certification schemes (VCS) have become a key governance mechanism affecting land-use decisions and land-use shifts (Sikor *et al.,* 2013) aiming to mitigate the negative impacts of agricultural expansion and intensification, including deforestation (Milder *et al.,* 2014; Tscharntke *et al.,* 2015), by promoting environmental and biodiversity-friendly practices at the farm level. Studies reveal increases in the abundance or species richness of a wide range of taxa, including birds and mammals, invertebrates and arable-land flora in certified farms (Hole *et al.,* 2005; Bengtsson *et al.,* 2005; Tuomisto *et al.,* 2012; Tayleur *et al.,* 2018), and ecosystem services (Supplementary Materials 6.2.2, Kremen *et al.,* 2002; Bengtsson *et al.,* 2005; Hutton & Giller, 2003), mainly due to lower agrochemical inputs (Aude *et al.,* 2003; Hutton & Giller, 2003; Pimentel *et al.,* 2005; Birkhofer *et al.,* 2008)

However, most certification schemes are too recent to evaluate detectable impacts (Tayleur *et al.,* 2018) and results on environmental and biodiversity performance are in many cases limited (Gulbrandsen, 2010; Gulbrandsen, 2009) or variable (Bengtsson *et al.,* 2005). In some cases, certification schemes have spurred more intensive and degrading land-use practice (Guthman, 2004; Klooster,

2010) and caused higher deforestation in neighbouring old-growth forest areas (Tayleur *et al.,* 2016).

A few studies have also documented positive livelihood outcomes from certification (Bacon, 2005; Bolwig *et al.,* 2009; Gulbrandsen, 2005; Ruben and Fort, 2012) and improved management institutions, but impacts on poverty alleviation are mixed (Yu Ting *et al.,* 2016). Many schemes have exacerbated problematic political and economic inequalities (Gómez Tovar *et al.,* 2005; Ponte, 2008) or failed to enhance market access or benefits (Font *et al.,* 2007), especially for smallholder farmers (DeFries *et al.,* 2017; Tayleur *et al.,* 2018). There are also issues of high transaction costs, transparency, legitimacy and equity in certification schemes (Supplementary Materials 6.2.2; Eden, 2009; Klooster, 2010; Havice & Iles, 2015; Hatanaka *et al.,* 2005).

Certification of tropical agricultural commodities shows clear aggregations in Central America, Brazil, West Africa and parts of East Africa and Southeast Asia and has poor representation in the world's 31 poorest countries (Tayleur *et al.,* 2018), and schemes remain limited in geographic scope (Ebeling & Yasué, 2009; Rametsteiner & Simula, 2003, Tayleur *et al.,* 2016).

Certification could better contribute to sustainability goals if targeted where benefits can be optimized (Tayleur *et al.,* 2016), i.e. areas of high nature conservation value (including landscape level quality) (Hole *et al.,* 2005), in areas of social and economic development priority, and where enabling conditions exist (e.g. governmental complementary policies) (Tayleur *et al.,* 2016). Governments can facilitate the impact of certification schemes by promoting certification uptake and supporting strategic targeting. Governments involved in international aid could engage in coordinating efforts to finance certification in identified priority areas for social and economic development (Tayleur *et al.,* 2016).

Public campaigns on the environmental, health, conservation, and social benefits of certified products are likely to increase consumer demand for these products, and measures aiming to enhance social responsibility in multi-national corporations can be effective (Tayleur *et al.,* 2018). Engaging in more equitable food value chains (see sections on *Improving food distribution and localizing food systems*, *Expanding food market transparency and price stability* and *Regulating commodity chains*) have the potential to expand the geographical range and enhance social outcomes. Critical to promoting VCS that balance conservation and economic demands is: 1) managing stakeholder expectations; 2) targeting priority habitats, species and social groups and 3) implementing adequate post-certification monitoring of impacts (Yu Ting *et al.,* 2016; Tayleur *et al.,* 2018). New technology (e.g., environmental data management and sharing infrastructure, modelling, web-based communication) and data availability could help improve monitoring and assessment of certification impacts, including bio-physical (e.g., nutrient leakage, water use efficiency, biodiversity), social and economic criteria.

Regulating commodity chains

Two major efforts to regulate commodity chains, particularly for tropical agricultural products, and to deal with telecoupling issues and the unsustainable expansion of these commodities include multistakeholder fora and commodity moratorium policies. Examples of multistakeholder fora are the Roundtable on Sustainable Palm Oil (RSPO), the Roundtable on Responsible Soy (RTRS) Better Sugar Cane Initiative, and the Roundtable on Sustainable Biomaterial, which aim to engage all private stakeholders of an agricultural supply chain, including growers; processors; consumer goods manufacturers; environmental NGOs; social NGOs; banks and investors; and retailers to establish a "sustainability" standard, and unlike labels that focus on a specific market, these standards envision to transform the entire sector towards sustainability. However, the RSPO standard overlooks the root causes of palm oil expansion in the tropics, such as land rights, commodity prices, agricultural systems and market access, resulting in a rather small and local level impact of certification on biodiversity conservation (Ruysschaert & Salles, 2014; Ruysschaert, 2016). At the global level, the RSPO is promoting a segregated landscape with large-scale plantations and conservation areas. This could make sense, as large oil palm plantations are very productive. However, this fails to recognize that the main environmental and social gains can be made by supporting smallholders, who currently produce half as much as the large-scale plantations (Ruysschaert, 2016; GRAIN, 2016).

Although the RSPO standards may be based on principles of inclusive participation from each member category; consensus building; and transparency in the negotiation process (RSPO, 2013, Schouten & Glasbergen, 2011), in practice, its implementation is more complex, with RSPO certification favouring three dominant groups of stakeholders: the downstream agro-business firms, international environmental NGOs, and the largest palm oil producers (Ruysschaert, 2016). For the downstream firms, RSPO certification fulfils their initial goal to secure their business in the long-term and protect their reputation (RSPO, 2002), but it often fails to cover costs of producers, particularly, the forgone economic opportunity to convert the areas identified as high conservation value (HCV) (Ruysschaert & Salles, 2014). RSPO has tended to favour large-scale producers seeking to get access to international markets; smaller firms and smallholders are largely excluded either because they sell to domestic markets where certification is not valued by consumers, or because they find certification too costly and its managerial requirements too demanding (Ruysschaert & Salles, 2014; Ruysschaert, 2016; and Supplementary Materials 6.2.2)

The case of moratoria such as the Brazilian Soy Moratorium (Supplementary Materials 6.2.2) appears to have been more successful in delivering biodiversity conservation outcomes (i.e. halting deforestation, Rudorff *et al.,* 2011; Gibbs *et al.,* 2015) and has set the stage for other initiatives to improve the sustainability of soy production and raise the awareness of the markets, like the RTRS and the Soja Plus Program. These initiatives are additional to zero-deforestation agreements and include other issues related to environmental compliance, social justice and economic viability at the farm and the supply chain level. Although there are leakage risks due to Moratorium restrictions (Arima *et al.,* 2011), recent analysis is showing no evidence for this (Le Polain de Waroux *et al.,* 2017). In contrast, there are opportunities for soy production in degraded pasture areas without increasing deforestation; combined with the identification of suitable areas, pasture intensification techniques and controlling new deforestation, the soy supply chain in the Amazon may become a good example of reconciliation of forest conservation and agricultural production. However, despite the good results, there are still threats to the Moratorium. Policy mixes supporting this package of measures can be enhanced if they address failures related to market shares, like the lack of engagement of traders and importers and the competition with farmers not covered by the Moratorium, which may further demise the motivation of the private sector in keeping the agreement.

Conserving genetic resources for agriculture

The diversity of cultivated plants, domestic animals and their wild relatives is fundamental for food security globally (Asia, Africa, Central and South America) (McConnell, 2003; Dawson *et al.,* 2013), and essential to the adaptation of agriculture to new and uncertain patterns of climate change. Most of the global genetic diversity in agriculture is kept in low-input farming systems (McConnell, 2003), and it is central to food sovereignty and to food as a non-material contribution to GQL (Chapter 1), also in IPLCs, where it can also involve cultural keystone species which support community identity and traditional roles (e.g. taro in the Pacific, corn in Central and South America, buffalo in North America). Globally, policy options to protect genetic resources for agriculture and forestry include support to on-farm conservation (*in situ*) (Enjalbert *et al.,* 2011; Thomas *et al.,* 2012, 2015) integrated with the conservation of germplasm in gene banks (*ex situ*). *In situ* conservation requires that the farmers, livestock keepers and foresters who conserve and manage these varieties, breeds and species benefit from maintaining this global common resource (CBD, 2014 Nagoya Protocol; Collette *et al.,* 2015). The genetic diversity in agriculture underlie current debates on food and seed sovereignty, and the implications of intellectual property rights to conservation of biodiversity and plant germplasm (Coomes *et al.,* 2015, see also Chapter 2.1 section 2.1.9.1.1). The debates have involved researchers, policy makers, seed producers for the market and IPLCs, bringing tension over seed legislation, regulation and commercialization (FAO, 2004; CBD The Nagoya Protocol, 2014; European Seed Association, 2014).

The case of social networks (e.g. farmer seed networks and community seed banks (Coomes *et al.,* 2015; Pautasso *et al.,* 2013; Lewis & Mulvany, 1997), illustrate the potential and challenges of the conservation and sustainable use of local genetic resources of global significance. Seed networks are cornerstones in maintaining the diversity of crops and their wild relatives (Tapia, 2000); they account for 80-90% of the global seed transfers and supply (Coomes *et al.,* 2015) and are important channels of innovation and diversity (Coomes *et al.,* 2015), and therefore show considerable potential for innovation and transformation of agricultural systems aligned with the SDG, especially if entry points for improvement are identified (Buddenhagen *et al.,* 2017). Seed networks are found in all regions of the world: Central and South America, Africa, Asia; in the Australia, Canada, the UK and the USA, and particular types of community seed banks have emerged (Vernooy *et al.,* 2015; Dawson *et al.,* 2011; Urzedo, 2016).

Options examined in the literature include aspects of seed quality and distribution, social and economic dimensions and global governance issues. Developing quality standards for traits, seeds and other material, and quality control schemes would considerably enhance the potential for integration into global processes of sharing and exchange of genetic resources (Coomes *et al.,* 2015; Jarvis *et al.,* 2011), but the mechanisms of seed sharing require attention, so that barriers that discriminate disfavored social groups can be addressed and eliminated (Tadesse *et al.,* 2016). Vernooy *et al.* (2017) summarize a series of measures to maintain *in situ* genetic diversity, which include support to local institutions, actively protect plants and livestock breeds that can survive extreme conditions, facilitate the restoration of varieties no longer used, develop platforms to facilitate access and availability of seeds at the community level, and help access novel diversity not conserved locally. Since in many cases, farmers have few market or non-market incentives, different public measures will be necessary to protect genetic resources (Jarvis *et al.,* 2011).

Given that these resources are of global importance (see also Chapter 2.2 section 2.2.3.4.3 on agro-biodiversity hotspots and Chapter 3 on Aichi Target 13) the national and global mechanisms need to be developed and harmonized. Global mechanisms are governed by three agreements originating from different sectors: The Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization under the CBD (CBD, 2014; Nagoya Protocol), the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (FAO, 2004), and the International Convention for the Protection of New Varieties of Plants (UPOV http://www.upov.int/portal/index.html.en). Despite efforts to harmonize implementation, there are considerable gaps in the coordination of the agreements.

Managing large-scale land acquisitions (LSLA)

Concerns about LSLA (also sometimes called "land grabbing") have increased considerably over the past decade (Borras *et al.,* 2011; Balehegn *et al.,* 2015) and include issues of food security, equity, leakage and environmental effects (Grant & Das, 2015; Coscieme *et al.,*, 2016; Borras *et al.,* 2011; Adnan, 2013). While some see land acquisitions as investments that can contribute to more efficient food production at larger scales (World Bank, 2010; Deininger & Byerlee, 2012), there are strong concerns that food security (especially at local levels) may be threatened by these large agribusiness deals (Daniel, 2011; Lavers, 2012; Golay & Biglino, 2013, Ehara *et al.,* 2018; and Supplementary Materials 6.2.2).

Displacement of smallholders from LSLA can potentially lead to impoverishment and increased (unsustainable) production elsewhere once they are removed from lands (Borras *et al.,* 2011; Adnan, 2013); these have happened with frequency in many countries in Africa, where communal land tenure authorities have allowed expropriation of locally used lands without other farmers' knowledge or compensation (Osinubi *et al.,* 2016). There is some evidence that LSLA have already led to the impoverishment of some communities and as many as 12 million people (Adnan, 2013; Davis *et al.,* 2014). In at least some cases, the causal process is that land grabs contribute to increased tenure insecurity in surrounding lands, leading farmers to shift to cultivating smaller farms with less investments, potentially leading to food shortages (Aha *et al.,* 2017). There is some evidence that land grabbing is also weakening local systems of common property management, which can make some communities less able to adapt to climate changes in the future (Gabay & Alam, 2017; Dell'Angelo *et al.,* 2017), including reducing the forest resources they may depend on as safety nets (Kenney-Lazar, 2012).

The primary policy mechanisms for combatting large scale land acquisitions have included restrictions on the size of land sales (Fairbairn, 2015); pressure on agribusiness companies to agree to voluntary guidelines and principles for responsible investment (Collins, 2014; Goetz, 2013); attempts to repeal biofuels standards (Palmer, 2014); and direct protests against the land acquisitions (Hall *et al.,* 2015; Fameree, 2016). REDD+ has the potential to provide a counterbalance with funding to combat land grabbing, but evidence is unclear if this is really happening yet or if REDD+ will mostly protect areas not under threat from large-scale investments (Ziegler *et al.,* 2012; Phelps *et al.,* 2013). Some have also accused REDD+ projects of being akin to land grabs in that they may displace smallholder agriculture without proper compensation (Lyons & Westoby, 2014; Corbera *et al.,* 2017). Future policies to regulate LSLA will need to rely on better monitoring data as a first step, as it is difficult to track the scale and impact of such LSLA.

Encouraging dietary transitions

The characteristics of today's global(ized) food system and the increasing industrialization of agricultural production, food consumption, and in particular animal protein consumption, are associated with a range of challenges, including food sovereignty, biodiversity loss, climate change, pollution, and animal health and welfare (HLPE, 2016; Steinfeld *et al.,* 2006; Garnett *et al.,* 2013; HLPE, 2016; Visseren-Hamakers, 2018; McMichael *et al.,* 2007; Jones & Kammen, 2011; Tilman & Clark, 2014). These problems are especially urgent given the fact that the global production of different animal products is expected to double by 2050 (Steinfeld *et al.,* 2006). The expansion of soybean in South America illustrates the challenges of current globalized industrial food production, with 45% of livestock feed in the EU based on soybean imported from Brazil and Argentina (EEA, 2017; Strada & Vila, 2015).

Current consumption of animal products is very unequally distributed, and animal protein can continue to play a role in ensuring food security in much of the developing world (Steinfeld & Gerber, 2010). However, substantially reducing the consumption of animal products in developed countries and emerging economies has the potential to greatly lower the negative impacts of farming while at the same time generating significant dividends in terms of people's health (Pelletier & Tyedmers, 2010; Smith *et al.,* 2013; Tilman & Clark, 2014; Bajzelj *et al.,* 2014; Ripple *et al.,* 2014; Springmann *et al.,* 2016, see also Chapter 2.3).

Different types of policy instruments aimed at lowering and changing consumption have been tried and studied (Story *et al.,* 2008; Vinnari & Tapio, 2012). Informational policy instruments aim to foster more sustainable food choices by offering information on production characteristics or health implications of food types or products. They range from certification schemes and (requiring) labels listing product ingredients or voluntary labels, signaling superior production methods (in terms of environmental, social or animal welfare aspects), to health campaigns (Reisch *et al.,* 2013), and would seem promising given a lack of consumer awareness of the implications of animal protein, an inaccuracy of messages on the health implications of (red) meat consumption, and the potential for altering relevant consumer attitudes and motivations identified by research (Boegueva *et al.,* 2017, Dagevos &Voordouw, 2013).

Economic policy instruments such as subsidies or taxes have been used to influence consumer choice via economic incentives and have shown to be particularly effective at driving dietary change, at least in developed countries (Dallongeville *et al.,* 2010; Capacci *et al.,* 2011; Mytton & Clarke, 2012; Thow *et al.,* 2014; Whitley *et al.,* 2018). Regulatory standards, in turn, prescribe what may be sold to consumers. However, the use of such policy instruments in the food sector has for the most part been restricted to the case of age-related prohibitions on the purchase of tobacco or alcohol (also see 6.4).

However, while the political *Zeitgeist* has favored informational policy tools, they often lack effectiveness. Studies have identified the prevalence of an attitude – action gap, and showed that structural constraints, such as information asymmetries and overflow as well as restrictions on time and other relevant resources by consumers, have prevented informational policy instruments from achieving major changes in food consumption patterns (Fuchs *et al.,* 2016; Horne, 2009). Among private certification schemes, those with the largest market shares often have little actual impact on the sustainability characteristics of a food product, as they tend to emphasize documentation rather than performance or fail to tackle the most impactful aspects of food production, distribution and consumption (Fuchs & Boll, 2012; Kalfagianni & Fuchs, 2015). Simultaneously, studies inquiring into the drivers of meat consumption have highlighted its promotion via advertising and media images that transport images of identity (especially masculinity, but also national and cultural identity) as well as artificially low meat prices (Bogueva *et al.,* 2017).

Thus, policy efforts to improve the sustainability of food consumption in general, and reduce animal protein consumption in particular, would require a policy mix reaching far beyond the (nudging of the) individual consumer (Fuchs *et al.,* 2013, 2016; Glanz & Mullis, 1988; Wolf & Schönherr, 2011). Such policies would need to focus on regulating the advertising of animal products, as well as sources of low meat prices, among others through lowering subsidies and enhancing (implementation of) animal welfare, labor and environmental standards. Simultaneously, policies could support (elements of) alternative food systems such as community-supported agriculture and different forms of farmers markets (Hinrichs & Lyson, 2007). Altering current dietary trajectories should not compromise the needs of low-income populations and of IPLCs and will face significant cultural and psychological barriers (Kuhnlein *et al.,* 2006; Whitley *et al.,* 2018).

Reducing food waste

Food waste currently runs at ~30-40% of all food production in developing and developed countries alike (Gustavsson *et al.,* 2011; Bond *et al.,* 2013; FAO, 2015, 2017; Bellemare *et al.,* 2017). Causes and hence possible solutions differ geographically, and they include more effective pest control (Oerke, 2006; Oliveira *et al.,* 2014), improved food distribution and better food storage in developing regions (Sheahan & Barrett, 2017), and consumer education (Kallbekken & Saelen, 2013; Aschemann-Witzel *et al.,* 2017; Young *et al.,* 2017) and less wasteful marketing practices in developed countries (Garrone *et al.,* 2014; Halloran *et al.,* 2014; Rezaei & Liu, 2017). Some countries, such as Japan, South Korea, Taiwan and Thailand have established operating systems that safely recycle more than one-third of their food waste as animal feed (Menikpura *et al.,* 2013; zu Ermgassen *et al.,* 2016; Salemdeeb *et al.,* 2017). However, several studies suggest an upper bound to feasible reduction in food waste of around 50% (Parfitt *et al.,* 2010; Bajzelj *et al.,* 2014; Odegard & van der Voet, 2014). Cutting food waste will thus require substantial changes in food supply chains and business models (Parfitt *et al.,* 2010; Papagyropoulou *et al.,* 2014; Aschemann-Witzel *et al.,* 2015; Roodhuyzen *et al.,* 2017).

Improving food distribution and localizing food systems

Localization of food systems is advocated by research (Hines, 2000) and by social movements, and has entered policy making at various levels (see e.g., the EU Regulation 1305/2013 on support for rural development or city-level food policies such as in Toronto or Manchester) emphasizing territoriality and sovereignty in food production and consumption. The major arguments supporting short food supply chains (SFSCs), beyond their socio-economic impacts such as revitalization of rural areas and local cultures (Brunori *et al.,* 2016; Schmitt *et al.,* 2017) are their potential to enhance food security and decrease food miles, the latter one addressing land-use change (less physical infrastructure for transportation), climate change (lower CO_2 emissions due to less transportation) and energy use (Mundler & Rumpus, 2012). However, the shortcomings of the local scale are also mentioned in literature, acknowledging that local is not necessarily better in terms of ecological sustainability, health, social justice etc. (Born & Purcell, 2006; Brunori *et al.,* 2016; Recanati *et al.,* 2016; Schmitt *et al.,* 2017). Evidence shows that the ecological impacts of SFSCs can be diverse, depending on the product type, the farming system (Rothwell *et al.,* 2016), the manner of transportation/logistics (Mundler & Rumpus, 2012; Nemecek *et al.,* 2016), the natural resources available locally and the actual social (Recanati *et al.,* 2016), economic and policy context (Leventon & Laudan, 2017).

Positive environmental impacts of SFSCs can be improved if the localization of agricultural production is coupled with: i) closing the loops between production, consumption and waste management (Benis & Ferrão, 2017; Sala *et al.,* 2017) (see also the section on circular economy in

6.4), ii) urban planning (integrating agriculture into the management of urban systems) (Barthel & Isendahl, 2013) through novel technological solutions that enable sustainable but more intensive food production (e.g., vertical gardens) (see also 6.3.5), iii) alternative food distribution options (e.g. social supermarkets or food banks) (Michelini *et al.,* 2018), iv) dietary changes as discussed below (Benis & Ferrão, 2017), and v) novel governance solutions across the food chain that enable more direct engagement of local communities in food production (Sonnino, 2017) and the (re)connection of various types of producers and consumers (Mount, 2012).

Expanding food market transparency and price stability

Food price increases during the 2007-08 world financial crisis resulted in severe impacts on the quality of life in many countries (Ivanic & Martin, 2008; Bellemare, 2015), leading many to assert that policies to increase food market transparency might lead to less volatility (Clapp, 2009; Minot, 2014). Policy responses to price increases have included reductions on food taxes and import tariffs, and increasing subsidies and food-based safety nets, although there is mixed evidence on which policies have been most effective in supporting poor populations (Wooden & Zama, 2010), indicating that social targeting is needed in combination with food support programs.

Public food procurement policies can also play a role in stabilizing price support for farmers. In Brazil, where government expenditures represent 20% of the GDP, two initiatives of public procurement of around US$300 million in expenditures are innovating to merge social and environmental targets. The Food Acquisition Program (created in 2003) and the National Program of School Feeding (created in 2009) have the purpose of: (i) providing healthy and balanced food respecting the culture, values and eating habits, especially for populations in socioeconomic vulnerability, and (ii) supporting the sustainable development of smallholding agriculture by incentives for producing local and seasonal food (Brazil, 2017). While the impact of these programs requires further evaluation, their goals to acquire locally produced food for school consumption while encouraging small-scale agricultural economies can be applicable in different contexts.

6.3.2.2 Sustainably managing multifunctional forests

Expanding and improving community-based forest management and co-management

Community-based forest management has emerged as a promising forest management alternative to state-controlled forest management (Charnley & Poe, 2007; Flint *et al.,* 2008; Krott *et al.,* 2014; Paudyal *et al.,* 2017). Almost one third of the forests in the Global South are now managed by IPLCs **(Figure 6.2)**, more than twice the share of protected areas (Chape *et al.,* 2005; RRI, 2014; Blackman *et al.,* 2017). Global trends towards decentralized management of forests, articulated through the active recognition of IPLCs rights to self-governance, have substantially improved the quality of life of forest-dependent communities, by providing them with greater livelihood benefits (Agrawal *et al.,* 2008; Gautam *et al.,* 2004; Larson & Soto, 2008; Phelps *et al.,* 2010; Duchelle *et al.,* 2014; RRI, 2014, 2016; Lawler & Bullock, 2017) including capital formation, governance reform, community empowerment and societal change (Pokharel *et al.,* 2007, 2015). Expanding and improving of community-based forest management have provided substantial opportunities for the conservation of forest ecosystems (Ostrom & Nagendra, 2006; Chazdon, 2008; Sandbrook *et al.,* 2010; Porter-Bolland *et al.,* 2012; Naughton-Treves & Wendland, 2014; van der Ploeg *et al.,* 2016; Asner *et al.,* 2017; Robinson *et al.,* 2017; Stickler *et al.,* 2017).

Many countries in Asia, such as the Philippines, Vietnam, Indonesia and Thailand have put forward new organizations, authorities and bottom-up approaches to promote community-based approaches to forest management (Sato, 2003; Poffenberger, 2006; Salam *et al.,* 2006; Sunderlin, 2006; Sikor & Tan, 2011), in the light of growing evidence of their effectiveness at contributing to poverty reduction (Ostrom, 1990; Brown *et al.,* 2003; Gautam *et al.,* 2004; Gilmour *et al.,* 2004; Gautam and Shivakoti, 2005; Sunderlin, 2006). These large areas managed by IPLCs do not usually attract financial and other resources akin to that provided for government-managed forest and protected areas. Moreover, there have been challenges in ensuring that communities have the right to benefit from co-management arrangements, such as from the sale of timber (Gritten *et al.,* 2015) and ensuring that IPLCs do not suffer from community forestry arrangements (such as in loss of food security or access to resources) (Sikor & Tan, 2011; Tuan *et al.,* 2017).

Forest titling programs have improved inclusion of settlers and secured alienation rights (Nelson *et al.,* 2001; Ostrom *et al.,* 2002; Pagdee *et al.,* 2006; Jacoby & Minten, 2007; Riggs *et al.,* 2016). However, forest tenure may not change management patterns without supporting the customary institutions of IPLCs that enforce exclusion rules and legitimize claims to them (Place & Otsuka, 2001; Ojha *et al.,* 2009; Kerekes & Williamson, 2010; Gabay & Alam, 2017).

Co-management of forest resources between the state and IPLCs, as well as other stakeholders, has also been promoted as an alternative to centralized governance approaches to achieve socio-economic and environmental objectives in developing countries (Carter & Gronow, 2005;

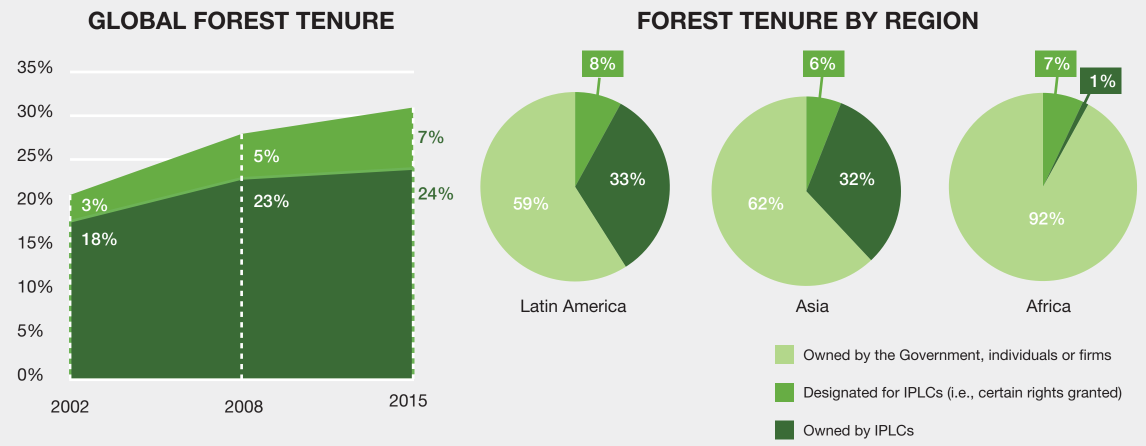

Figure 6 2 **Global patterns of forest owned by and designated for IPLCs.**
Source: RRI (2016).

Kothari *et al.,* 2013; Akamani & Hall, 2015). As forests are common-pool resources from which the exclusion of potential users is difficult, achieving sustainable forest management can be regarded a collective responsibility, especially in developing countries where the government has limited capacity to implement appropriate forest policy and needs support of diverse stakeholders (Sikor, 2006; Ostrom, 2010; Pokharel *et al.,* 2015). In the above context, collaborative governance is an appealing arrangement for sustainable forest management because of its potential to combine strengths of different management approaches and stakeholders (Carter & Gronow, 2005; Fernández-Giménez *et al.,* 2008).

Improving policies relating to PES and REDD+

There has been a rapid expansion in the number of payments for ecosystem services (PES) schemes and projects globally over the past 20 years, and many decision makers, from governments to NGOs, are considering either initial experimentation or continued expansion of PES. There is a great diversity of institutional configurations in PES arrangements, many of which involve a strong role of the state (McElwee, 2012; Shapiro-Garza, 2013). However, the effectiveness of PES approaches is currently unknown, namely because they are interpreted and implemented in many different ways (Borner *et al.,* 2017; Salzman *et al.,* 2018). Overall, the literature indicates that PES approaches are not a panacea (Muradian *et al.,* 2013), due to high preparation and transaction costs, uneven power relations, and distribution of benefits (Porras *et al.,* 2012; Salzman *et al.,* 2018; Berbés-Blásquez, 2016; Cáceres *et al.,* 2016; Van Hecken *et al.,* 2017). In other words, the performance of PES depends not just on economic incentives but also on other factors like motivations and environmental values (Hack, 2010; Hendrickson & Corbera, 2015; Grillos, 2017). Lessons learned from the literature on these economic financing instruments for conservation include the need to have in place strong regulatory frameworks; have clear metrics and indicators; have motivated buyers and sellers of services; recognize pluralistic value systems alongside financial considerations; acknowledge the importance of distributional impacts when designing economic instruments; and recognize that economic approaches are not a panacea (Ezzine-de-Blas *et al.,* 2016; Robalino & Pfaff, 2013; Pascual *et al.,* 2017; Hack, 2010; Hendrickson & Corbera, 2015; Grillos, 2017; van Hecken *et al.,* 2017; Salzman *et al.,* 2018; see also section 6.3.4.5 on watershed PES)

One important PES-like initiative is REDD+ (Reducing Emissions from Deforestation and forest Degradation), part of the negotiations under the UNFCCC since 2005 as a climate mitigation strategy to compensate developing countries for reducing GHG emissions from deforestation and forest degradation. REDD+ also aims to contribute to poverty alleviation of smallholders (through sale of carbon credits or direct forest products) and biodiversity conservation. Carbon forestry projects have expanded particularly rapidly in Latin America (Osborne, 2011; Corbera & Brown, 2010; Rival, 2013) and Africa (Namirembe *et al.,* 2014). However, the literature is currently mixed on the success rates of forest carbon projects in general and REDD+ has faced a number of challenges. These include a lack of a strong financial mechanism to ensure sufficient funding and demand for credits (Turnhout *et al.,* 2017), the high costs involved in setting up REDD+ projects (Luttrell *et al.,* 2016; Bottazzi *et al.,* 2013; Visseren-Hamakers *et al.,* 2012a), meeting the technical requirements of REDD+ (Turnhout *et al.,* 2017; Cerbu *et al.,* 2013) and REDD+'s ability to deliver non-carbon benefits such as biodiversity conservation (Hall *et al.,* 2012; Venter *et al.,* 2013; Duque *et al.,* 2014; Murray *et al.,* 2015) and social livelihoods (Atela *et al.,* 2015; Boyd *et al.,* 2007; Reynolds, 2012; Caplow *et al.,* 2011; Lawlor *et al.,* 2013). REDD+ has also been observed to contribute to a recentralization of forest governance by bringing forests under renewed forms of government control, with potentially negative consequences for nature, NCP and GQL (Ribot *et al.,* 2006; Phelps *et al.,* 2010; Sunderlin *et al.,* 2014; Duchelle *et al.,* 2014; Vijge & Gupta, 2014; Abidin 2015).

The future of REDD+ depends on its ability to safeguard against negative side effects of REDD+ and ensure that forests continue to deliver noncarbon benefits (Chhatre *et al.,* 2012; Visseren-Hamakers *et al.,* 2012b; Tacconi *et al.,* 2013; Luttrell *et al.,* 2013, Ojea *et al.,* 2015). As part of this, REDD+ will need to be inclusive of multiple values and perspectives, including historical, cultural and spiritual values (Gupta *et al.,* 2012; Brugnach *et al.,* 2014). This will require adequate formal arrangements for the participation of IPLCs. This involvement is crucial, since IPLCs control substantial areas of tropical forests (Anon, 2009; Bluffstone *et al.,* 2013). However, arrangements for participation by IPLCs in REDD+ policies are not clear in most country readiness plans for REDD+, despite safeguard guidance from UNFCCC (Ehara *et al.,* 2014), and participation has generally been weak in pilot activities, with many communities only consulted, rather than being involved in a systematic manner in all aspects of REDD+ planning (Hall, 2012; Brown, 2013). There is evidence that projects where IPLCs have been included from the beginning are stronger (Chernela, 2014). There is also potential for inclusion of IPLCs in community-based carbon monitoring, which has proven accurate and low cost (Danielsen *et al.,* 2013; Pratihast *et al.,* 2013; Brofeldt *et al.,* 2014; McCall *et al.,* 2016). See Supplementary Materials 6.2.3 for a detailed discussion on PES and REDD+.

Supporting Reduced Impact Logging (RIL)

More responsible logging practices, such as Reduced Impact Logging (RIL), are options to avoid deforestation and forest degradation. RIL, which involves close planning and control of harvesting operations, has increased in importance in the past decades. Such logging practices lower the ecological impacts of logging, especially on biodiversity (Bicknell *et al.,* 2017; Chaudhary *et al.,* 2016; Martin *et al.,* 2015). For example, in a study in East Kalimantan in Indonesia, application of RIL techniques have been found resulting in nearly half (36 vs 60 trees per ha) of collateral damage of trees as compared to the conventional harvesting methods (Sist, 2000). RIL techniques along with postharvest silvicultural treatments have also been found effective in enhancing canopy tree growth and regeneration and controlling invasion by alien and undesirable species (Campanello *et al.,* 2009). Moreover, improved logging practices in tropical forests can substantially reduce forest carbon loss and enhance retention (Putz *et al.,* 2008).

Promoting and improving forest certification

Forest certification, an economic instrument introduced in the early 1990s to improve forest management, can help address the concerns of deforestation and forest degradation and promote conservation of biological diversity especially in the tropics by promoting sustainable forest management and establishing deforestation-free supply chains (Rametsteiner & Simula, 2003; Auld & Gulbrandsen, 2008; Damette & Delacote, 2011). For instance, certification has been found to have positive impacts in terms of ecological outcomes (forest structure, regeneration, and lower fire incidences) (Kalonga *et al.,* 2015; Pena-Claros *et al.,* 2009) and biodiversity conservation in some places (Van Kuijk *et al.,* 2009; Kalonga *et al.,* 2016). Positive social impacts, such as better working and living conditions, active local institutions for discussions among the forestry company and local communities, and benefit sharing have also been documented (Cubbage *et al.,* 2010; Cerutti *et al.,* 2014; Burivalova *et al.,* 2016). There has also been criticism of different certification schemes, and forest certification more generally, among others on the fact that most certified forests are in the global North, instead of the South (Rametsteiner & Simula, 2003), in part due to the technical and financial demands for becoming certified can represent a hurdle for small and medium-sized enterprises in the South. For instance, current certification schemes tend to favor large forestry operations and do not directly translate to smaller operations. While there is still limited evidence of the impacts of different forest certification schemes (Visseren-Hamakers & Pattberg, 2013), improved assessment practices are suggesting ways forward (van de Ven and Cashore, 2018).

Controlling illegal logging

Illegal logging, which can be viewed as a symptom of failure of governance and law enforcement, is a major problem in achieving sustainable forest management in many countries, particularly forest-rich developing countries (Brack & Buckrell, 2011). Forest dependent poor people are the most harmed by illegal logging while powerful economic groups benefit the most from it (ODI, 2004). International trade in illegally logged timber is an important factor associated with this problem (Brack & Buckrell, 2011). In recent years, however, consumer countries have been paying increasing attention to trade in illegal timber and have taken different measures to exclude illegally produced timber from the market. The European Union's Action Plan for Forest Law Enforcement, Governance and Trade (FLEGT), published in 2003, is an example of such measures. The FLEGT regulations and approaches have often been combined with improved management of concessions in countries participating in FLEGT through Voluntary Partnership Agreements with the EU (Tegegne *et al.*, 2014). Apart from the European Union's Timber Regulation 995/2010, some other countries, including Australia, Indonesia, Japan and USA, have their own law to control illegal logging (Hoare, 2015).

Monitoring and regulating forest use

The development and availability of transparent forest monitoring data is a major step to establish and improve the forest sector (Fuller, 2006). By identifying the extent of deforestation on a regular basis, decision makers have the option to coordinate actions, prioritize areas and develop policies to reduce forest losses. In the Brazilian Amazon, where the deforestation was substantially reduced from 2004 to 2017 (INPE, 2017), the understanding of forest change patterns was essential to allocate public resources and to provide the first reaction to the illegal processes that were leading to deforestation in that region. The monitoring systems have been improved to the point of offering daily real-time data, constituting one of the most important tools for the fight against deforestation in Brazil (Nepstad *et al.,* 2014; Assunção *et al.,* 2015). Also, global initiatives like the Global Forest Watch are supporting national and sub-national governments to implement national law (as in the case of the law Nr 26331on "Minimum Standards of Environmental Protection of Native Forests" in Argentina), as well as civil society and private sector engagement in forest monitoring and conservation (FAO, 2015; GFW, 2017). Reforestation projects have contributed to reversing the deforestation trend and increasing forest cover in some countries (Supplementary Materials 6.2.3). Especially REDD+ and PES schemes have contributed to expand reforestation and afforestation projects in recent years (Carnus *et al.,* 2006; Madsen *et al.,* 2010). REDD+ projects have expanded particularly rapidly in Latin America (Osborne, 2011; Corbera & Brown, 2010; Corbera & Brown, 2008) and Africa (Jindal *et al.,* 2012; Namirembe *et al.,* 2014).

Land tenure recognition and cadastral registers are tools that contribute to the implementation of regulations aimed to protect forest and support reforestation actions. For instance, the Rural Environmental Registry (CAR) in Brazil records and analyses information about land use and environmental compliance in all private properties. CAR registration is mandatory and linked to official credit support, environmental licensing and regularization. It is also used in voluntary agreements for trading agricultural products and facilitating the process of forest restoration to reach legal compliance (Soares-Filho *et al.,* 2014; Servicio Florestal Brasileiro, 2016). The implementation of the CAR system in Brazil is an example of confronting the simultaneous challenges of monitoring, enforcement and compliance, and reconciling forest and water conservation and other production sectors, particularly agriculture.

Forest concessions can also be an option to protect forest cover and regulate use, reducing the pressure to replace the natural vegetation with other land uses. Concessions give the holder rights, including harvesting timber (or other forest products) and use of forest services (e.g. tourism, watershed protection) (Gray, 2002). Concessions, if properly governed, can be an important instrument to provide economic value to forests and reduce the pressure to replace the natural vegetation with other land uses around the world. Besides employment and revenue creation, forest concessions may reinforce the presence of the state and improve the rights over land tenure (FAO, 2015). Concessions are also a good governance tool for the state, considering the establishment of conditions and compensation, such as the development of local services (schools, medical assistance, security) and infrastructure (water supply, transport, roads, bridges). This instrument can be applied not only by entrepreneurs and companies, but also by IPLCs with different land tenure regimes (van Hensbergen, 2016). Poorly governed concession schemes, however, can drive deforestation and marginalize local communities. Governments can enhance the contributions of forest concessions by requiring participatory planning, long-term sustainable forest management, and control of illegal logging.

Problems of forest concessions in tropical countries are related to weak local governance, poor level of compliance, difficulties with monitoring and traceability systems, low technical capacity of managing the forest, and insufficient rewards for sustainable forest management in the global timber market (Azevedo-Ramos *et al.,* 2015; van Hensbergen, 2016; Segura-Warnholtz, 2017). Therefore, forest concessions are often regarded drivers of forest degradation (PROFOR, 2017). Corruption in attaining timber concessions is another problem associated with this instrument, especially in developing countries. There are initiatives of implementing monitoring and traceability systems, but it is important to manage the bureaucracy and additional transaction costs that may deter potential investors (Azevedo-Ramos *et al.,* 2015).

6.3.2.3 Protecting nature within and outside of protected areas

Improving management of protected areas

There is a large literature that has evaluated the performance of protected areas (PAs) in halting biodiversity loss and securing ecosystem services into the future, showing mostly positive (albeit moderate) conservation outcomes (Carranza *et al.,* 2014; Barnes *et al.,* 2016; Eklund *et al.,* 2016; Gray *et al.,* 2016). However, research also points to substantial shortfalls in PA effectiveness around the world (Laurance *et al.,* 2012; Guidetti *et al.,* 2014; Watson *et al.,* 2014; Geldmann *et al.,* 2015, 2018; Schulze *et al.,* 2018). Poor PA performance is attributed to management deficiencies related to inadequate resources and weak governance. It also includes low compliance due to inhibited local access to important resources (Stoll-Kleemann, 2010; Bennett & Dearden, 2014; Bruner *et al.,* 2001; Eklund & Cabeza, 2016; Leverington *et al.,* 2010; Watson *et al.,* & Hockings, 2014). Evidence shows that improving PA effectiveness depends on enforcing sound management (Juffe-Bignoli *et al.,* 2014), monitoring (Schulze *et al.,* 2018) and adequate resourcing (McCarthy *et al.,* 2012). Using robust methods, such as those available via the global Protected Areas Management Effectiveness (PAME) initiative, controlling potential bias, and integrating data on ecological outcomes (e.g. temporal and spatial counterfactual analysis) and social indicators could make the assessment of PA effectiveness more systematic and comparable across spatial and temporal scales, addressing the needs of different decision makers more effectively (Coad *et al.,* 2015; Eklund *et al.,* 2016; Stoll-Kleemann, 2010; Watson *et al.,* 2016) for all decision makers.

PAs generate multiple benefits to both local and distant populations (Chan *et al.,* 2006; Ceausu *et al.,* 2015; Egoh *et al.,* 2011; Larsen *et al.,* 2012; Schröter *et al.,* 2014a), and provide fundamental contributions such as protecting watersheds, buffering extreme events, regulating local climate, harboring biodiversity, and providing spaces of emotional, social and spiritual fulfilment. Protected areas and these multiple contributions also have associated costs in limiting and regulating land uses and forms of access to resources (Birner & Wittmer, 2004; Holzkamper & Seppelt, 2007; Wätzold *et al.,* 2010; Wätzold & Schwerdtner, 2004; Nalle *et al.,* 2004). Balancing the benefits and costs of PAs across different stakeholders can increase the management effectiveness of PAs (see also Supplementary Materials 6.2.4). Options include co-management governance regimes (i.e. sustainable-use PAs), which engage communities in maintaining cultural and livelihood benefits (Oldekop *et al.,* 2016), and jointly consider approaches to mitigating conflicts and managing trade-offs. PA effectiveness can also be enhanced by supporting local households to establish or find alternative livelihood and income options (i.e., improving options and capabilities; Neudert *et al.,* 2017), supporting benefit-sharing mechanisms that eliminate inequalities (Swemmer *et al.,* 2017) and securing the availability of financial resources to support these measures for a sufficiently long period to ensure sustainability (Wätzold *et al.,* 2010).

Improving spatial and functional connectivity of PAs

The functionality of PA networks cannot be maintained when the habitat area is too small and fragmented, and when the landscape beyond PA boundaries is inhospitable (Bengtsson *et al.,* 2003). PAs then become islands of biological conservation (Bauer & Van Der Merwe, 2004; Crooks *et al.,* 2011; Seiferling *et al.,* 2012; Barber *et al.,* 2014; Wegmann *et al.,* 2014) threatening the long-term viability of their biodiversity, especially many wildlife populations (DeFries *et al.,* 2005; Newmark, 2008; Riordan *et al.,* 2015). There are also significant geographic and ecological biases in the representation of habitats and ecosystems in PAs (e.g., Pressey *et al.,* 2003; Joppa & Pfaff, 2009, Butchart *et al.,* 2012, 2015), which result in unplanned assemblages of PAs confined to economically unproductive areas (Scott *et al.,* 2001; Evans, 2012), with little ecological relevance (Opermanis *et al.,* 2012), which ultimately compromise their overall conservation potential (Watson *et al.,* 2014).

Options to address these challenges include several policy support tools for (spatial) conservation prioritization to inform where to establish new PAs so that more biodiversity is conserved in a cost-effective way, accounting for multiple competing sea- or land uses and socioeconomic factors (e.g., Dobrovolski *et al.,* 2014; Forest *et al.,* 2007; Isaac *et al.,* 2007; Montesino Pouzols *et al.,* 2014; Nin *et al.,* 2016; Di Minin *et al.,* 2017). Spatial conservation planning can be a useful tool for enhancing landscape connectivity, maximizing the ecological representation of PA networks and safeguarding Key Biodiversity Areas (Edgar *et al.,* 2008; Krosby *et al.,* 2010, 2015; Dawson *et al.,* 2011; Cabeza, 2013; Dickson *et al.,* 2014, 2017; Kukkala *et al.,* 2016; Watson *et al.,* 2016; Saura *et al.,* 2018). Research has estimated that only 19.2% of the ~15,000 Key Biodiversity Areas identified around the world are fully protected, and that the proportion of the PAs comprising these areas is decreasing over time (Butchart *et al.,* 2012; UNEP-WCMC & IUCN, 2016). Therefore, protected areas are being disproportionately established in areas that are suboptimal from a biodiversity conservation point of view (Butchart *et al.,* 2012, 2015). Shifting PA establishment to focus on Key Biodiversity Areas is thus an important policy priority to reverse extinction risk trends.

Building on the expansion of PAs under Aichi Biodiversity Target 11, the next phase of global biodiversity targets offers an excellent opportunity to correct some of the geographic biases of establishing PAs in recent decades, often based on local and opportunistic criteria (Pressey *et al.,* 2003; Joppa & Pfaff, 2009; Lewis *et al.,* 2017). Especially the conservation of world's old-growth forests can be addressed in Multilateral Environmental Agreements, as targets for PA expansion (e.g., Watson *et al.,* 2018). Expanding PAs requires managing trade-offs among societal objectives, and improvement can be achieved with global coordination (DeFries *et al.,* 2007; Polasky *et al.,* 2008; Faith, 2011; Venter *et al.,* 2014) and consultation of different stakeholders.

Improving transboundary PA and landscape governance

Options to enhance PA effectiveness also need to address conservation planning and management at broader geographic scales (van Teeffelen *et al.,* 2006; Le Saout *et al.,* 2013; Kukkala *et al.,* 2016). Transboundary conservation planning is essential to improve the global status of biodiversity (Erg *et al.,* 2012; Pendoley *et al.,* 2014; Dallimer & Strange, 2014; Lambertucci *et al.,* 2014), particularly for wide-ranging species that cannot be conserved within political boundaries, such as large carnivores (Wikramanayake *et al.,* 2011; Wegmann *et al.,* 2014; Santini *et al.,* 2016; Di Minin *et al.,* 2017), species that migrate (Flesch *et al.,* 2010; Runge *et al.,* 2015; Owens, 2016) and species that might shift their range in response to climate change (Wiens *et al.,* 2011; Zimbres *et al.,* 2012; Johnston *et al.,* 2013; Pavón-Jordán *et al.,* 2015).

Research shows that setting conservation targets in a spatially coherent manner beyond national borders is vital for improving the effectiveness of PA networks (van Teeffelen *et al.,* 2015; Wegmann *et al.,* 2014). Different works have demonstrated a major efficiency gap between national and global conservation priorities, finding that if each country sets its own conservation priorities without international coordination, more biodiversity is lost than if conservation decision-making is done through international partnerships and globally coordinated efforts (Montesino-Pouzols *et al.,* 2014; Santini *et al.,* 2016). The European Union's Natura 2000 network of PAs provides an illustrative example of joint initiatives crossing political and national boundaries. With more than 27,000 sites across all EU countries, covering over 18% of the EU's land area and almost 6% of its marine environments, Natura 2000 is the most expansive coordinated network of PAs in the world (Milieu *et al.,* 2016). It is the cornerstone of the EU's Biodiversity Strategy to 2020, and one of the largest policy efforts in conserving biodiversity irrespective of national and political boundaries. A plethora of research studies has evidenced the overall ecological effectiveness of Natura 2000, with a special emphasis on terrestrial vertebrates and threatened habitats (Gruber *et al.,* 2012; Pellissier *et al.,* 2013; Kolecek *et al.,* 2014; Sanderson *et al.,* 2016; Beresford *et al.,* 2016; Milieu *et al.,* 2016). The Greater Mekong Subregion Biodiversity Conservation Corridors Project or the Mesoamerican Biological Corridor are also key initiatives illustrating the importance of transboundary conservation planning at the landscape level (ADB, 2011; Mendoza *et al.,* 2013; Crespin & García-Villalta, 2014). Policy options to promote transformative change towards sustainability in the Arctic include the application of new, multi-sector frameworks for integrated ecosystem management (Pinsky *et al.,* 2018), the establishment of a circumpolar network of Protected Areas (Fredrikson, 2015) and the proposal for the creation of a global Arctic sanctuary in the high seas (European Parliament, 2014; Greenpeace, 2014).

Recognizing management by IPLCs and OECMs

The conservation of a substantial proportion of the world's biodiversity and NCP largely depends on the customary institutions and management systems of IPLCs (Maffi, 2005; Gorenflo *et al.,* 2012; Gavin *et al.,* 2015; Renwick *et al.,* 2017; Garnett *et al.,* 2018). Evidence suggests that IPLCs are able to develop robust institutions to govern their land- and seascapes in ways that align with biodiversity conservation (ICC, 2008, 2010; Stevens *et al.,* 2014; Ens *et al.,* 2015, 2016; Trauernicht *et al.,* 2015; Blackman *et al.,* 2017; Schleicher *et al.,* 2017). These customary institutions and management systems are based on locally-grounded knowledge and encoded in complex cultural practices, relational values, usufruct systems, spiritual beliefs, kinship-oriented philosophies, and principles of stewardship ethics (Berkes *et al.,* 2000; Bird, 2011; Gammage, 2011; Kohn, 2013; Walsh *et al.,* 2013; Trauernicht *et al.,* 2015; Gaudamus & Raymond-Yakoubian, 2015; Fernández-Llamazares *et al.,* 2016; Renwick *et al.,* 2017).

Formal recognition of IPLC rights over their territories can be an effective means to significantly slow habitat loss (Nepstad *et al.,* 2006; Soares-Filho *et al.,* 2010; Ricketts *et al.,* 2010; Porter-Bolland *et al.,* 2012; Nolte *et al.,* 2013; Paneque-Gálvez *et al.,* 2013; Ceddia *et al.,* 2015; Blackman *et al.,* 2017). The growing recognition of governance diversity in global environmental policy offers numerous opportunities for sound management of nature and its contributions to the larger society (Berkes, 2009; Kothari *et al.,* 2012; Ruiz-Mallén & Corbera, 2013; Nilsson *et al.,* 2016), while improving the quality of life of IPLCs, including addressing some of the human rights violations associated with the establishment and governance of some PAs (e.g., Brockington & Igoe, 2006; Goldman, 2011; Kohler & Brondizio, 2016). Certain strict PAs have induced displacements and exclusion of IPLCs (West *et al.,* 2006; Mascia & Claus, 2008; Curran *et al.,* 2009; Agrawal & Redford, 2009; Brockington & Wilkie, 2015), undermining food sovereignty (Golden *et al.,* 2011; Foale *et al.,* 2013; Nakamura & Hanazaki, 2016; Sylvester *et al.,* 2016) and contributing to psychological distress and trauma (Dowie, 2009; Zahran *et al.,* 2015; Snodgrass *et al.,* 2016).

A crucial breakthrough in conservation paradigms over the last decades has been the emergence and growing awareness of a number of IPLC-centred designations to conservation, including co-management regimes, community-based conservation areas, integrated conservation and development projects, sacred natural sites, Indigenous Community Conserved Areas (ICCAs), and biocultural approaches to conservation (e.g., Berkes, 2004, 2007, 2009; Folke *et al.,* 2005; Armitage *et al.,* 2007;

Kothari *et al.,* 2013; Brooks *et al.,* 2013; Gavin *et al.,* 2015; Alexander *et al.,* 2016; Berdej & Armitage, 2016; Sterling *et al.,* 2017). Many of these approaches will contribute a substantial share of the world's "Other Effective Area-Based Conservation Measures" (OECMs) such as proposed under Aichi Target 11 (Jonas *et al.,* 2014, 2017; Laffoley *et al.,* 2017; Garnett *et al.,* 2018).

Sacred natural sites, as a specific example of OECMs, are areas of land or water that have spiritual values to certain IPLCs (Thorley & Gunn, 2007; Ormsby, 2011). They contribute to the conservation of diverse habitats and species as well as traditional land use practices (Salick *et al.,* 2007; Metcalfe *et al.,* 2009; Gavin *et al.,* 2015; Samakov & Berkes, 2017). Their governing institutions are diverse, including informal norms, rules and taboos passed on by generations (Anthwal *et al.,* 2010; Bhagwat & Rutte, 2006b; Bobo *et al.,* 2015; Ya *et al.,* 2014), and are under increasing pressure from globalization (Bhagwat & Rutte, 2006; Virtanen, 2002; Domínguez & Benessaiah, 2015; Fernández-Llamazares *et al.,* 2018). Sacred natural sites have been combined with legal and economic instruments, often with controversial results (Bhagwat & Rutte, 2006b; Brandt *et al.,* 2015). Appropriate legal recognition of sacred natural sites has been deemed as a critical factor to ensure their effectiveness in conserving nature and NCP (Davies *et al.,* 2013; Smyth, 2015; Mwamidi *et al.,* 2018). Specific legal recognition of sacred natural sites builds on prior broader recognition of collective IPLC tenure rights and self-determination (Kothari, 2006; Berkes, 2009; Almeida, 2015; Borrini-Feyerabend & Hill, 2015). However, there is evidence that top-down forms of recognition, without consultation often undermine local initiative and grassroots action (Borrini-Feyerabend *et al.,* 2010; Kothari *et al.,* 2013). Best practice cases indicated that knowledge-sharing and mutual learning are key success factors when sacred sites are recognized as OECMs (Aerts *et al.,* 2016b; Irakiza *et al.,* 2016; Jonas *et al.,* 2018).

Addressing the Illegal Wildlife Trade (IWT)

Despite intense worldwide efforts, the Illegal Wildlife Trade (IWT) still represents a major threat to endangered species. Research shows the major strengths and weaknesses of efforts to address the IWT. CITES currently lacks a global enforcement agency to oversee compliance, which has been argued to compromise its overall effectiveness (Phelps *et al.,* 2010; Heinen & Chapagain, 2002; Oldfield, 2003; Zimmerman, 2003; Reeve, 2006; Toledo *et al.,* 2012; Challender *et al.,* 2015). Further, CITES enforcement within countries is often sporadic at best, with many developing countries lacking the knowledge and identification facilities to help control and report illegal trade (Zhang *et al.,* 2008; Shanee, 2012). The International Consortium on Combating Wildlife Crime (ICCWC) has helped in providing support to countries in the fields of policing, customs, prosecutions and the judiciary, (e.g., through the creation of the ICCWC Wildlife and Forest Crime Analytical Toolkit; UNODC, 2012) and informing IWT decision-making (Nellemann *et al.,* 2014; Sollund & Maher, 2015). In the meantime, research shows that intergovernmental initiatives at the regional level, such as the ASEAN Wildlife Enforcement Network, including 10 Southeast Asian countries, and EU-TWIX, an online forum and database on IWT patterns within the European Union, are also essential for assisting national law enforcement agencies in detecting and monitoring IWT across national borders (Rosen & Smith, 2010; Sollund & Maher, 2015). Civil society and NGO support, such as through TRAFFIC, has been essential for many countries to keep their mandatory reporting requirements for CITES up to date (Reeve, 2006).

Some studies are examining where resources could best be prioritized for improved protected area management and law enforcement, as well as to disrupt shipping routes of IWT (Kiringe *et al.,* 2007; Plumptre *et al.,* 2014; Ihwagi *et al.,* 2015; Patel *et al.,* 2015; Tulloch *et al.,* 2015; Lindsey *et al.,* 2017). Improving detection capacity for "invisible" wildlife trades, through improved data, capacity-building and implementation of innovative technologies such as DNA barcoding and stable isotope analysis, is often cited as a global priority for IWT control (Phelps *et al.,* 2010; Nijman & Nekaris, 2012; Phelps & Webb, 2015; Symes, 2017).

Prioritization of IWT in criminal justice systems has generally led to more effective law enforcement responses (Lowther *et al.,* 2002; Sollund & Maher, 2015; EIA, 2016; Jayanathan, 2016). Similarly, increases in anti-poaching patrols in protected areas generally leads to significant declines in levels of poaching (Dobson & Lynes, 2008; Jachmann, 2008; Fischer *et al.,* 2014; Critchlow *et al.,* 2016; Henson *et al.,* 2016; Moore *et al.,* 2017). Implementing measures to combat corruption among rangers, crime investigators and other relevant officials and civil servants, is also deemed critical to halt IWT (Smith & Walpole, 2005; Bennett, 2015; UNODC, 2016). Also, IPLCs are important allies in global efforts to combat IWT on the ground (Roe, 2011; MacMillan & Nguyen, 2013; Ihwagi *et al.,* 2015; Cooney *et al.,* 2016; Humber *et al.,* 2016; Benyei *et al.,* 2017; Biggs *et al.,* 2017; Massé *et al.,* 2017; Roe *et al.,* 2017), although they often suffer from blanket hunting bans established at local levels that do not discriminate between endangered and common animals (McElwee, 2012) as well as use of trade bans to address other threats such as climate change (Weber *et al.,* 2015). Similarly, both NGO and research presence have been shown to deter wildlife poaching, particularly in areas with minimal governmental surveillance (Hohman, 2007; Pusey *et al.,* 2007; Campbell *et al.,* 2011; N'Goran *et al.,* 2012; Laurance, 2013; Mohd-Azlan & Engkamat, 2013; Daut *et al.,* 2015; Piel *et al.,* 2015; Sollund & Maher, 2015; Tagg *et al.,* 2015).

Finally, well-targeted, species-specific and evidence-based demand reduction policy interventions for illegally-sourced wildlife and its products are also growing in scope and extent, on the understanding that legally-sourced products are managed sustainably based on CITES non-detriment findings, and harvested and traded in accordance with national and international laws (CITES, 2017; Moorhouse *et al.,* 2017). Social marketing strategies (e.g. discouraging rhino horn consumption in Vietnam through TV ads with celebrities) coupled with broad outreach and educational campaigns, are a common strategy to change consumer behaviour (Drury, 2009, 2011; Dutton *et al.,* 2011; Gratwicke *et al.,* 2008a; Veríssimo *et al.,* 2012; Challender & MacMillan, 2014; TRAFFIC, 2016; Truong *et al.,* 2016), although evidence on the effectiveness of such policies is still virtually lacking (MacMillan & Challender, 2014; Challender *et al.,* 2015). Regular online monitoring of e-commerce platforms, websites and social media offers substantial opportunities for the enforcement of IWT regulations (Izzo, 2010; Hansen *et al.,* 2012; Lavorgna, 2015; TRAFFIC, 2015).

Improving Sustainable Wildlife Management (SWM)

Sustainable Wildlife Management (SWM) is an essential tool to conserve wildlife while considering the socioeconomic needs of human populations, including IPLCs (Gillingham & Lee, 1999; Spiteri & Nepal, 2006; Pailler *et al.,* 2015; Riehl *et al.,* 2015; Campos-Silva & Peres, 2016) and the generation of multiple contributions to people (Holmlund & Hammer, 1999; Díaz *et al.,* 2005; Kremen *et al.,* 2007; Whelan *et al.,* 2008, 2015; Kunz *et al.,* 2011; Moleón *et al.,* 2014; Ripple *et al.,* 2014; Poufoun *et al.,* 2016). Several best practices in fostering SWM (e.g., mitigating human-wildlife conflicts) have emerged over the last decades (Brooks *et al.,* 2013; FAO, 2016; Nyhus, 2016), and the debate increasingly includes animal welfare aspects, among others under the heading of "compassionate conservation" (Bekoff, 2013).

Both *incentive-driven* and *financial compensation* schemes can contribute widely to nature conservation and benefit sharing with IPLCs and provide economic compensation for those bearing most of the costs of maintaining public benefits associated with biodiversity conservation (Naughton-Treves *et al.,* 2003; Maclennan *et al.,* 2009; Persson *et al.,* 2015; Dhungana *et al.,* 2016, Supplementary Materials 6.2.4). However, the effectiveness of wildlife compensation schemes in conserving nature and contributing to local quality of life varies (Boitani *et al.,* 2010; Ravenelle & Nyhus, 2017). Some works show that wildlife compensation schemes can reduce conflict (Zabel & Hom-Müller, 2008), reduce wildlife killings (Okello *et al.,* 2014) and recover wildlife populations (Persson *et al.,* 2015), particularly in contexts where IPLCs are facing acute subsistence needs or with wildlife that imposes disproportionate costs. However, several pitfalls and operational issues undermine the effectiveness of wildlife compensation payments mostly related to their administration, including crowding-out effects, unequal distribution of benefits, elite capture, corruption or leakage (e.g., Bulte & Rondeau, 2005; Ogra & Badola, 2008; Spiteri *et al.,* 2008; Agarwala *et al.,* 2010; Uphadyay, 2013; Anyango-Van Zwieten, *et al.*, 2015). Also, some authors have questioned their financial sustainability in the long-term (Nyhus *et al.,* 2003; Bulte & Rondeau, 2005; Swenson & Andrén, 2005; Bauer *et al.,* 2015). In general, research highlights that wildlife compensation schemes are not a silver-bullet solution, although they might be indeed valuable in certain contexts and under certain conditions (Haney, 2007; Dickmann *et al.,* 2011; Ravenelle & Nyhus, 2017). *Conservation performance payments*, conditional on specific conservation outcomes (e.g., bird breeding success), have been argued to partially address some of the operational challenges of incentives focusing on compensation for losses to predation (Zabel & Holm-Müller, 2008).

Nature-based tourism is another revenue-generating use of certain wildlife that can provide incentives for IPLCs to conserve biodiversity in appropriate contexts (Bookbinder *et al.,* 1998; Kiss, 2004; Hearne & Santos, 2005; Lindsey *et al.,* 2005; Lai & Nepal, 2006; Stronza, 2007; Osano *et al.,* 2013). IPLCs with economically viable ecotourism programs linked to wildlife are likely to steer SWM (Stem *et al.,* 2003; Krüger, 2005; Clements *et al.,* 2010; Mendoza-Ramos & Prideaux, 2017), but only when benefits are culturally-appropriate and equitably distributed (Bookbinder *et al.,* 1998; Naidoo & Adamowicz, 2005; He *et al.,* 2008), land tenure is secured (Charnley, 2005; Haller *et al.,* 2008; Bluwstein, 2017), the social and political justice aspirations of IPLCs are respected (Stronza & Gordillo, 2008; Coria & Calfucura, 2012), and the value conflicts introduced by tourism development are fully addressed (Lai & Nepal, 2006; Waylen *et al.,* 2010).

Although financial benefits to sustain SWM have often been prioritized (Tisdell, 2004; Ogra & Badola, 2008), incentives to engage IPLCs in SWM can also include education, empowerment and opportunities for capacity development (Nabane & Matzke, 1997; Brooks *et al.,* 2009), social services and infrastructure (Spiteri & Nepal, 2006), as well as devolution of IPLC rights to manage, and benefit from, wildlife conservation (Lindsey *et al.,* 2009; Western *et al.,* 2015; Nilsson *et al.,* 2016). Moreover, engaging women in SWM as direct beneficiaries and key stewards of wildlife can help bridging the agendas of gender equality and SWM, particularly within the framework of the SDG (Nabane & Matzke, 1997; Espinosa, 2010; Staples & Natcher, 2015; FAO, 2016; UNEP, 2016; Leisher *et al.,* 2016; Lelelit *et al.,* 2017). Gender mainstreaming approaches are crucial for the success of community-based SWM (Ogra, 2012; Meola, 2013; UNESCO, 2016; Davies *et al.,* 2018).

Manage invasive alien species through multiple policy instruments

There are more than 40 international legal instruments dealing with the issue of invasive alien species (IAS), including CITES and the Ramsar Convention on Wetlands, as well numerous national laws. However, there are many legal, institutional and social barriers to effective invasive species management, including information management challenges, resourcing, risk perception and lack of public support, and definitional and jurisdictional issues that can generate a lack of coherent, systemic and community-partnered approach to IAS management. This is particularly the case in urban and peri-urban areas where rapid urban growth and sprawl occurs (Martin *et al.,* 2016; Le Gal, 2017; Riley, 2012; Vane and Runhaar, 2016). Further, low economic incentives to engage private landowners can undermine the effectiveness of the frameworks for IAS management and biodiversity protection (Martin *et al.,* 2016). Developing and implementing IAS management strategies in collaboration with IPLCs has been suggested as an effective means to enhance local capacity to prevent, detect and eradicate IAS in areas inhabited or managed by IPLCs, although the evidence still lies on weak empirical footing, with only a few case-based studies available (e.g., Hall, 2009; Dobbs *et al.,* 2015). It is well established that social, political and economic values, as well as cultural worldviews have been shown to underlie the perception of IAS, as well as preferences over management options (O'Brien, 2006; Warren, 2007; Hall, 2009; Crowley *et al.,* 2017). In view of this, direct inclusion of IPLCs on deliberations over IAS management decisions can help to identify the most strategic and effective measures for IAS control, as well as to anticipate conflict and foster dialogue over different values in inclusive ways (Robinson *et al.,* 2005; Bhattacharyya *et al.,* 2014).

Potential solutions include treating IAS as a collective action problem rather than a private landowner problem (Martin *et al.,* 2016; Graham *et al.,* 2016; Graham, 2013; Howard *et al.,* 2016), implementing projects for removal of IAS through direct payments (Bax *et al.,* 2003; McAlpine at al., 2007; Rumlerova *et al.,* 2016; Brown *et al.,* 2016), through tax incentives combined with restoration work and tradeable permits (see examples in Supplementary Materials 6.2.4).

6.3.2.4 Expanding ecosystem restoration projects and policies

Ecological restoration is *the process of assisting the recovery of an ecosystem that has been degraded, damaged,* or destroyed (SER, 2004) and reforestation can have potential positive impacts to help ecosystems adjust to climate change, such as through restoring altered hydrological cycles, extending habitat for species threatened by climate change, or protecting coastal areas from storms and sea level rise (Locatelli *et al.,* 2015). For instance, the UN is committed to restoration through projects such as reforestation for carbon sequestration (e.g. REDD+) (Nellemann & Corcoran, 2010; Watson *et al.,* 2000; Munasinghe & Swart, 2005) or restoring wetlands for flood protection. There is wide agreement on the importance of expanding restoration efforts, including the CBD Aichi Target 15 that commits to restoration of at least 15% of degraded ecosystems by 2020, the European Union Biodiversity Strategy Target 2, and the Bonn Challenge to restore 150 and 350 million hectares of the world's deforested and degraded lands by 2020 and 2030, respectively. Restoration and reforestation of 12 million ha of forests by 2030 are also key elements of the implementation of the Brazilian Nationally Determined Commitments (NDC) of the Paris Agreement.

Restoration projects make use of both regulatory and market instruments in policy mixes, such as public financing, mitigation banking or offsetting, tax incentives, and performance bonds (Hallwood, 2006; Reiss *et al.,* 2009; Robertson, 2004; Ruhl *et al.,* 2009). Tax incentives for set-asides for restoration work, such as Landcare & Bushcare policies (in Australia), are farmer voluntary policies that encourage community-based strategic restoration projects (Compton and Beeton, 2012), including bush set-asides for recovery from grazing and grants to replant and fence off bushland. Farmers pay for at least half the restoration costs, which can be reclaimed through tax incentives (Abensperg-Traun *et al.,* 2004). The Working for Water Program in South Africa is an example of an approach that combines IAS removal and restoration through targeted employment and payments to poorer participants. The project has been credited with success in native vegetation species recovery (Beater *et al.,* 2008; van Wilgen & Wannenburgh, 2016) and increasing water yields (Le Maitre *et al.,* 2000, 2002; Dye & Jarmain, 2004). Lessons from the South Africa program include the need for continuous monitoring and frequent follow-up, the need to train personnel, and the need for active restoration (and replanting) of native tree species on cleared plots. Another national example of integrating restoration objectives into specific policies is that of the Rural Environmental Registry (CAR), which supports the implementation of the new Forest Law in Brazil (see section on Monitoring and regulating forest use above).

Contextual and historical legacies often shape restoration practices. Therefore, there is increasing recognition that restoration projects need to be seen as part of larger social-ecological systems (Dunham *et al.,* 2018; Zingraff-Hamed, 2017), also considering social goals in the planning, decision-making, implementation and success evaluation of such projects (Junker, 2008; Hallett *et al.,* 2013; Higgs, 2005; Burke & Mitchell, 2007; Woolsey *et al.,* 2005;

2007). It is for example increasingly recognised that it is beneficial to involve all relevant stakeholder groups to gain acceptance (Junker *et al.,* 2007) and to promote social and environmental learning (Pahl Wostl, 2006; Restore, 2013; Petts, 2006). One example is the 're-wilding' approach in the US (Swart *et al.,* 2001; Hall, 2010) to restore to pre-European settlement ecosystems, which contrasts with the cultural landscape approach in Germany (Westphal *et al.,* 2010). The importance of community culture and normative values in shaping social acceptance of restoration projects has often been neglected (Ostergren *et al.,* 2008; Waylen *et al.,* 2009), with acceptance depending on whether restoration builds upon the emotional or cultural attachments that communities have to a place or supports traditional patterns of use (Baker *et al.,* 2014; Buijs, 2009; Drenthen, 2009; Lejon, 2009; Shackelford *et al.,* 2013). Participation, such as through community reforestation, is seen to reduce the risk of conflict (Eden and Tunstall, 2006; Gobster and Barro, 2000; Higgs, 2003) and promises more equitable outcomes, such as access to ecosystem services. This opens restoration as a tool for poverty alleviation. However, there is a knowledge gap in defining measures for social-economic attributes, although this has recently received attention (Baker & Eckerberg, 2016). Overall, there is a need for more research into the realized social and economic outcomes or impacts of restoration (see Supplementary Materials 6.2.4).

Revitalizing ILK and restoring IPLC institutions

Evidence shows that indigenous and local knowledge (ILK) is rapidly changing and eroding in many parts of the world (Cox *et al.,* 2000; Brodt, 2001; Godoy *et al.,* 2005; Brosi *et al.,* 2007; Turner & Turner, 2008; Reyes-García *et al.,* 2007, 2013, 2014; Tang & Gavin, 2016; Aswani *et al.,* 2018). While ILK is inherently dynamic (Berkes, 1999; Gómez-Baggethun & Reyes-García, 2013; Reyes-García, *et al.*, 2016), it has been shown that at least some dimensions of the social-ecological memory of IPLCs are becoming substantially eroded (Ford *et al.,* 2006, 2010; Turvey *et al.,* 2010; Fernández-Llamazares *et al.,* 2015). Rapid social and cultural changes create discontinuity in the transmission of ecological knowledge (Singh *et al.,* 2010; Etiendem *et al.,* 2011; Reyes-García *et al.,* 2010, 2014; Turvey *et al.,* 2010; Shen *et al.,* 2012; Guèze *et al.,* 2015; Luz *et al.,* 2015, 2017), impact the functioning of collective institutions, many of which have supported sustainable resource management and diverse biocultural landscapes for long periods of time (Agrawal, 2001; Oldekop *et al.,* 2013; Fernández-Llamazares *et al.,* 2016, 2018; Sirén, 2017).

Policies focused at revitalizing language and local ecological knowledge also contribute to recognizing and, in some cases, restoring IPLCs' customary institutions for ecosystem management, which have been weakened or eroded (Aikenhead, 2001; McCarter *et al.,* 2014; McCarter & Gavin, 2014; Tang & Gavin, 2016). For example, in contexts where environmental degradation is linked to the loss of cultural values, ILK revitalization efforts have been successfully linked to ecological restoration projects, also providing cultural incentives (Anderson,1996; Long *et al.,* 2003; López-Maldonado & Berkes, 2017; Reyes-García *et al.,* 2018). Some customary education programs have also integrated ILK in school curricula, contributing to strengthen networks of ILK transmission (Kimmerer, 2002; Reyes-García *et al.,* 2010; Ruiz-Mallén *et al.,* 2010; McCarter & Gavin, 2011, 2014; Hamlin, 2013; Abah *et al.,* 2015). Similarly, it has been shown that ILK revitalization efforts are most effective when controlled and managed by the communities involved (Singh *et al.,* 2010; McCarter *et al.,* 2014; Fernández-Llamazares & Cabeza, 2017; Sterling *et al.,* 2017). Moreover, it is important that revitalization efforts consider the gendered nature of knowledge and the crucial role of women in knowledge transmission (Iniesta-Arandia *et al.,* 2015; Díaz-Reviriego *et al.,* 2016).

6.3.2.5 Improving financing for conservation and sustainable development

Financing is a critical determinant of the success or failure of conservation outcomes, as acknowledged in the CBD and SDG which call for increased financing and aid, and Aichi Target 3, which calls for the promotion of positive incentives for the conservation and sustainable use of biodiversity by 2020. These economic tools for biodiversity can include instruments such as biodiversity-relevant taxes, charges and fees; tradable permit schemes; and subsidies that aim to reflect the inherent values of biodiversity in their actual use, which have raised billions in recent years (OECD, 2010b; OECD, 2013). Currently, finance mobilized to promote biodiversity has been estimated at about US$ 52 billion globally (Parker *et al.,* 2012; Miller, 2014), while estimates of the financing necessary to reach international targets range from US$ 76-440 billion per year (CBD, 2012; McCarthy *et al.,* 2012). An estimated 80 percent of biodiversity conservation funding across low and middle income countries is derived from international aid (ODA), with the remaining 20 percent coming from domestic, private and other sources (Hein *et al.,* 2013; Waldron *et al.,* 2013). Other forms of financing besides ODA include direct payments to those who conserve biodiversity through various transfer mechanisms, including PES (see section on *Improving REDD+ and PES,* above), eco-compensation policies, or ecological fiscal transfers (see Supplementary Materials 6.2.4 for details on the latter two). Other financing mechanisms can include tradable permits, in which markets, auctions or other schemes allow those causing biodiversity loss or pollution to compensate their environmental impacts in other locations (see Supplementary Materials 6.2.4).

Though uncertainty exists on overall funding levels (Tittensor *et al.,* 2014), there is widespread agreement that resources are well below needs (James *et al.,* 1999; McCarthy *et al.,* 2012; Waldron *et al.,* 2013) and have failed to meet donor commitments (Miller *et al.,* 2013). Developing country capacity to finance conservation and sustainable use is increasing (Vincent *et al.,* 2014), and initiatives such as the UNDP BIOFIN project (www.biodiversityfinance.net) have assisted countries with identifying options, but ODA is likely to remain the major finance source for now. Existing flows have generally been well-targeted to countries with greater conservation need (Miller *et al.,* 2013), but there is inconclusive evidence about whether these resources have resulted in conservation success. New trust fund and collective fund approaches have been used in recent projects, such as the Amazon Fund to combat deforestation in Brazil (see Supplementary Materials 6.2.4). However, few if any peer-reviewed studies explicitly examine the impact of specific biodiversity financing projects using robust program evaluation methods. Bare *et al.* (2015) find higher rates of forest loss correlated with aid (concluding not that aid caused loss, but that aid was insufficient to halt existing drivers), while Waldron *et al.* (2017) found that conservation funding —much of it is ODA—did reduce biodiversity loss by an average of 29%. There is a paucity of impact evaluations in the conservation sector that examine socio-economic impacts of financing (Börner *et al.,* 2016; Puri *et al.,* 2016). Finally, there is a major gap in assessing the long-term impacts of conservation aid (Miller *et al.,* 2017) (see also Supplementary Materials 6.2.4). All of these gaps suggest a strong need for better systems of tracking and assessing the impacts of different types of financing; in other words, not just more financing is needed, but better understanding of the mechanisms for success.

6.3.3 Integrated Approaches for Sustainable Marine and Coastal Governance

Marine and coastal areas, covering 70% of the Earth's surface, include the High Seas or areas beyond national jurisdiction (ABNJ) which cover nearly half of the Earth's surface (Harris & Whiteway, 2009) and territorial waters from the baseline to national territorial limits. Adding river catchments affecting coastal areas means that much of the Earth's surface is directly connected to marine and coastal biodiversity and ecosystem services. Policy instruments for coastal biodiversity and ecosystem management span the scale of institutions from global and intergovernmental to local communities, and concern many different sectoral, thematic and cultural stakeholder and rights-holder groups. The United Nations Convention on the Law of the Sea (UNCLOS) includes provisions for coastal States to exercise national jurisdictions within 200 nautical miles from the baseline and to meet responsibilities for their Flag vessels on the High Seas.

Most Aichi Biodiversity Targets are relevant to marine and coastal biodiversity, but Targets 6, 7, 10, and 11 are explicit in their coverage of fisheries sustainability and ecosystem-based management (Target 6), sustainable aquaculture (Target 7), and coral reefs subject to anthropogenic pressures and impacted by climate change and ocean acidification (Target 10), and protected areas (Target 11). The ambitious target dates of 2015 (Target 10) and 2020 (Target 6, 7 and 11) have not or will not be met globally by 2020. For the SDG, Goal 14 (life below water) is most explicitly relevant to marine and coastal biodiversity, but most other Goals are also relevant.

At the frontier between land and seas, coastal areas support dense human populations, are undergoing rapid economic development and have been heavily transformed e.g., into cities, ports, tourist facilities and aquatic farms, with profound consequences for biodiversity and ecosystem services such as wildlife habitats and clean water. Downstream of terrestrial material flows, deltas and estuary systems receive nutrient, sediment, sewage, waste and pollution loads from distant regions. On land and sea margins, climate and other hazards are often more severe than inland (United Nations World Ocean Assessment, 2017). Coastal rehabilitation offers some opportunities to partially restore some ecosystem functions after their initial transformation or destruction for human use.

Climate change and pollution caused by land and sea-based carbon emissions and waste disposal are impacting the High Seas and coastal areas. Direct human exploitation of the High Seas is also increasing from fishing, shipping, oil and gas extraction, seabed mining, ocean energy production and aquaculture. Consequently, biodiversity conservation is a key issue in the High Seas (World Ocean Assessment, 2017; Ingels *et al.,* 2017). High Seas biodiversity is experiencing predominantly negative impacts, e.g., Census of Marine Life (Ausabel *et al.,* 2010), including in the abundance and diversity of fauna and in the status of sensitive and unique habitats such as seamounts (Koslow *et al.,* 2017), hydro-thermal vents (LeBris *et al.,* 2017) and deep-sea corals (Cordes *et al.,* 2017).

The use and management of coastal and marine areas are divided among many individual and corporate players whose activities impact the oceans. Unless action is based on sound shared knowledge, the players may fail to act in the interests of conservation (World Ocean Assessment, 2017), e.g., when coastal reclamation projects proceed in ignorance of the potential destruction of ecosystem services. In addition, the rights of different players may be unequal. For example, IPLCs are often long-established inhabitants and users of the coastal environment, but their access and ownership often are not secured against larger economic activities.

Following the Rio 1992 Earth Summit, conservation groups, governments and researchers increased attention to fisheries and other coastal industries impacting biodiversity and ecosystem services (Spalding *et al.,* 2013; Garcia *et al.,* 2014). Despite the raised awareness, action has been slow. For example, despite the ocean's importance in climate, oceans will be a major priority only in the 6th assessment cycle of the IPCC, due for completion in 2022. After ten years of discussion, in 2017, the UN General Assembly resolved (Resolution 72/249) to convene a conference to develop an international legally binding instrument under UNCLOS in order to address the conservation and sustainable use of marine biodiversity of ABNJ and marine genetic resources benefits sharing.

Governance of marine conservation still faces major challenges including a lack of proper international and regional legal framework for emerging challenges such as the impact of climate change on marine biodiversity.

Another major problem is non-implementation of existing legal instruments in international, regional and national levels. Cases that illustrate these problems have been exposed in the IPBES regional assessments. For instance, the regional assessment for Europe and Central Asia highlights that, although the Regional Seas Conventions are playing an important role in joint management of marine areas, the performance is uneven and application not consistent with modern conservation principles and capacity of the region (IPBES, 2018a). The regional assessment for Asia and the Pacific highlights the absence of regional seas conventions or other binding legal instruments for promoting regional joint governance of marine areas (chapter 6, pp. 520-525).

This section presents both short and long-term policy options contributing to integrated approaches to marine and coastal governance. This ranges from identifying governance gaps, including in legal frameworks, and conditions that may facilitate the implementation of available policies in response to immediate needs **(Table 6.4)**.

Table 6 4 **Options for integrated approaches for marine and coastal governance.**

Short-term options	Long-term options (in the context of transformative change)	Key obstacles, potential risks, spillover, unintended consequences, trade-offs	Major decision maker(s)	Main level(s) of governance	Main targeted indirect driver(s)
Global marine and coastal					
Implementing global marine environment agreements for shipping		• Industry resistance due to competitive pressures, lack of awareness and lack of commitment • Practical weaknesses undermining the agreement effectiveness, e.g., flag state enforcement of MARPOL • More enterprises operating outside legal regimes	• International (e.g., IMO) • Regional (inter-) governmental organisations, • national, sub-national and local governments, including government linked authorities, e.g., port management • Shipping and logistics industry	International, regional, national, local	Economic, institutions
	Mainstreaming climate change adaptation and mitigation into marine and coastal governance regimes	• Lack of scientific knowledge to design practical measures • Lack of funding, industry and government support • Risk of resource declines, loss of human living space, food Lack of governance mechanisms to coordinate responses on necessary scales	• International inter-governmental agencies, • International and regional funding bodies • Regional and national sectoral agencies • Conservation-directed public-private financiers • Science and educational agencies • Donor agencies • IPLCs	International, regional, national, local	Economic, institutions, governance, technological

Short-term options	Long-term options (in the context of transformative change)	Key obstacles, potential risks, spillover, unintended consequences, trade-offs	Major decision maker(s)	Main level(s) of governance	Main targeted indirect driver(s)
	Mobilising conservation funding for the oceans	• Lack of private sector funding and very high reliance on public funds • Lack of investment assurance • Need for innovative financing mechanisms	• Maritime industries • International and national, governments	International, national	Economic, institutions, governance
International waters: High Seas (ABNJ) and regional waters					
Improving shared governance		• Maritime territory disputes • Ocean grabbing and failure to fully incorporate human dimension in conservation and resource governance • Differences in legal regimes of adjacent regions	International, regional, national and local governments	International, regional, national, local	Economic, institutions, governance, regional conflicts
Mainstreaming nature and its contributions to people		• Low national priority to biodiversity conservation • Current sectoral conservation efforts often need scaling up • Enforcement costs high, but electronic methods offer new options • Conservation and sectoral agency efforts need greater coherence	• International, regional and national governments, management agencies, NGOs, industry, IPLCs, Consumers	International, regional, national	Economic, institutions, technological, governance
	High Seas convention	• No legally binding international law for comprehensive protection of biodiversity	• International and national governments, • Non-governmental agencies, • Private sector	International, national	Economic, institutions, governance
Coastal waters					
Promote integrated management		• Long time frame and planning often stronger than implementation; • High transactions costs or fixed trade-offs can make system slow to respond to changing pressures or needs of coastal communities	• National central, sectoral agencies, NGOs, local and sub- national agencies, private sector specific to context, IPLCs	National, local	Economic, institutions, technological, governance
Mainstreaming nature conservation in sectoral management, with an emphasis on fisheries		• Widespread overfishing, pollution and habitat destruction, subsidies, IUU, market incentives • Weak progress in implementing existing fisheries governance framework • Solutions are context specific	• National governments, private sector management options, regional and international organisations, NGOs, industries and fishers organisations	International, regional, national	Economic, patterns of production, supply and consumption, governance, technological
Scaling up from sub-national project pilots		• Local conservation needs often precede national policies, but scaling up local solutions enables cooperation across local jurisdictions • Locally developed solutions may not be fully transferrable to other local situations	• National and local governments, IPLCs, Citizen groups	National, local	Economic, institutions, governance

Short-term options	Long-term options (in the context of transformative change)	Key obstacles, potential risks, spillover, unintended consequences, trade-offs	Major decision maker(s)	Main level(s) of governance	Main targeted indirect driver(s)
Building ecological functionality into coastal infrastructure		• Ineffective planning and approval processes for development • Insufficient financial and human resources for monitoring	• National and local governments, private sector	National, local	Economic, institutions, governance
Engaging stakeholders to achieve common ecological and social good outcomes		• Stakeholders not working together on solutions	• International and national NGOs, private sector governments, scientists and educationists, IPLCs	International, national, local	Economic, institutions, governance, cultural

6.3.3.1 Global Marine and Coastal

Overarching global policies and processes, including and beyond climate change-related agreements have had major impacts on action to protect marine and coastal biodiversity and ecosystem services (chapter 2.1 and 3). In the present section, we focus on key global agreements that need to be integrated into policy for marine and coastal biodiversity and ecosystem services.

6.3.3.1.1 Implementing global marine environment agreements for shipping

History shows that global agreements regarding shipping are challenging to negotiate, and, once agreed and ratified, challenging to implement, and in motivating government, industry and community stakeholders to act. The existing conventions and protocols on vessel-sourced pollution, including exotic and potentially invasive species from ships' hull fouling and ballast water, are important examples as shipping grows (World Ocean Assessment 2017, chapter 17).

Several international maritime agreements on the environment pre-dated UNCLOS, notably the International Maritime Organization (IMO) International Convention for the Prevention of Pollution from Ships, 1973 – MARPOL (Karim, 2015). UNCLOS was critical, however, as it introduced the regulatory framework of duties and jurisdiction of states addressing the main sources of ocean pollution, the success of which heavily depends on detailed regulations and their enforcement by international, regional and national institutions. Despite wide convergence of shipping issues and participation of most of the countries as well as the considerable success of IMO Conventions, worldwide uniform enforcement, monitoring and control still need development (Karim, 2015). Enforcement, monitoring and control relied greatly on flag state enforcement (Mattson, 2006) but in addition, port-state enforcement is being applied in some maritime agreements, such as the Food and Agriculture Organization Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (2009). This combined with new satellite and information technologies are being applied in efforts to track compliance, but enforcement is still weak (Petrossian, 2015). Enforcement and implementation are lacking both within and beyond national jurisdiction (Karim, 2015, 2018), but regional cooperative arrangements may improve regulatory capacity and should be further strengthened. In addition, a coordinated and widespread initiative for capacity building to strengthen understanding of and capacity for flag state responsibility in the global regulatory apparatus is needed to combat pollution in the areas beyond national jurisdiction (World Ocean Assessment, 2017).

6.3.3.1.2 Mainstreaming climate change adaptation and mitigation into marine and coastal governance regimes

Coordinated measures are needed to combat climate-related stressors on marine biodiversity, e.g., ocean acidification, ocean warming and deoxygenation (Bijma *et al.,* 2013; Pörtner, 2014; Levin *et al.,* 2018), as these stressors have sectoral effects, such as on stable fisheries agreements (Brandt & Kronbak, 2010; Galaz *et al.,* 2012). In fact, the Paris Agreement is now the first climate agreement to explicitly consider the ocean. International and regional legal instruments and mechanisms for climate change, oceans, fisheries and the environment are relevant for these challenges, but they remain inadequate (Galland *et al.,* 2012; Herr *et al.,* 2014; IPCC, 2017). At the least, sectoral and general ocean governance will have to mainstream major climate issues in governance regimes at international, regional and national levels. This mainstreaming will help sectoral management adapt and mitigate emissions. If linked to climate actions, this may also help reduce some of the knowledge gaps on climate and the ocean, and gaps between scientific and government attention to climate change (Magnan *et al.,* 2016; Gallo *et al.,* 2017). Achieving policy coherence over such complex issues also requires significant new knowledge on the oceans and climate which can feed back into climate science. In the case of proposed climate solutions such as geoengineering to capture carbon from the atmosphere, the IPCC warns that the impacts on marine ecosystems "remain unresolved and are not, therefore, ready for near-term application" (http://www.ipcc.ch/ipccreports/tar/wg3/index.php?idp=25).

Many impacts of global changes are highly unbalanced, because telecouplings affect people who have not caused the problems. Sea level rise is eroding the living space of many marginal coastal people in developing countries, e.g., on low-lying Pacific islands and coastal mangroves in Asia. Funds set up to address these transfer issues, e.g., the Green Climate Fund and other multilateral instruments will not have their intended effects unless greater priority is given to developing countries (Friends of the Earth and Institute for Policy Studies, 2017), and these funds need to specialize and cooperate effectively to provide coherent support (Amerasinghe *et al.,* 2017).

6.3.3.1.3 Mobilising conservation funding for the oceans

According to some estimates, the oceans provide trillions of USD annually in goods and services to society (Costanza *et al.,* 1997). Policies and incentives towards the sustainable use of the oceans – from controlling overfishing and pollution to promoting new technologies for energy and carbon sequestration to incentives for sustainable tourism – have economic and social impact across sectors of society and regions, benefiting private and public economies, and local communities. However, innovative solutions are needed for improving financing for conservation action for the ocean. Some estimates suggest that that market-based mechanisms could, for example, deliver up to 50% of the finance for coral reefs (Parker *et al.,* 2012), including for instance cap-and-trade programs such as the Ocean Appreciation Program (Ocean Recovery Alliance, 2016), green bonds (Thiele, 2015a), and blue carbon sequestration to benefit biodiversity (Maldonado & Barrera, 2014; Murray *et al.,* 2011; Thiele & Gerber, 2017). On the High Seas, the financial mechanisms to support conservation are not well established and new institutional financial structures, including financial solutions that allow for private funds to be invested in conservation, such as from international markets, are increasingly recognized as essential (Madsbjerg, 2016).

The majority of current biodiversity funding is from public finance (e.g., GEF) (Huwyler *et al.*, 2014) and is affected by the short-term time horizons of political agendas and public opinions. Following models used in climate (Buchner *et al.,* 2015) and development finance (Gutmann & Davidson, 2007), growing attention is given to the potential use of market-based mechanisms used in terrestrial systems for the High Seas, such as payments for ecosystem services and biodiversity offsets (Gjertsen *et al.,* 2014).

Clean, renewable ocean-derived energy has the potential to reduce carbon emissions and meet 10 percent of EU demand by 2050 (Ocean Energy Europe, 2015). Technologies of this magnitude, however, are impeded by high initial investments and risks. These barriers may be overcome through public-private collaboration and require careful planning and environmental impact assessment (Economist Intelligence Unit 2015). There is potential for increased research and infrastructure support for wave and tidal energy technology, which have been slow in terms of technological advancements (REN21, 2018; Bruckner *et al.,* 2014).

A portion of the profits from ocean-based goods and services could be directed into conservation research, monitoring, and enforcement. For example, ocean tourism, managed with respect for, with and by local communities, can yield successful results if earning from tourism are funneled into supporting sustainable management (Cisneros-Montemayor *et al.,* 2013; Hess, 2015); and appropriate incentives in fishing could help change current practices such as derelict gear that threaten habitats and natural capital stocks (Grafton *et al.,* 2006; Grafton *et al.,* 2008).

Global cooperation is needed to develop innovative mechanisms to conserve the ocean, just as global collaboration is needed to address air quality and atmospheric emissions. Ocean conservation projects may be funded by a proposed Ocean Bank for Sustainability and Development and trust funds. The Ocean Bank concept has been supported by several NGOs that argue current development banks and structures are not sufficient for the largest ecosystem (WWF, 2015). Proponents envision that this new institution arrangement could be funded by states and private investors, providing knowledge, project development, training, and financing (Cicin *et al.,* 2016). Trust funds can offer long-term financial assistance and have already been applied to marine conservation management (MAR Fund, 2014; MRAG, 2016), e.g., a fund for a protected area in Kiribati compensates the government for license profits forgone (MRAG, 2016).

In the last 20 years, conservation organisations – international, national and local – e.g., IUCN, WWF, CI, TNC, WCS and their local chapters – have developed major coastal conservation programs, supported by funding from (mainly) US based philanthropic foundations (Packard, Walton, Pew, etc.) and often giving particular attention to charismatic ecosystems, e.g., coral reefs, and mega-fauna, e.g., whale shark, cetaceans and other marine mammals, and penguins. However, as the foundations turn more to Blue Economy issues such as fishing and food security, their future efforts may not be so focused on biodiversity conservation, calling attention to the importance of diversifying funding mechanisms supporting marine and ocean conservation and sustainable use.

6.3.3.2 International waters: High Seas (ABNJ) and regional waters

Significant areas of the ocean are outside settled national jurisdictions, although certain activities may be under the controls of regional bodies or of global agreements. Some disputes over precise jurisdictions remain. A few countries, including the USA, have not signed the United Nations Convention on the Law of the Sea (UNCLOS), but largely abide by its provisions. The High Seas sustain global-scale ecosystem functions and provide essential benefits to humans (Rogers *et al.,* 2014) but are subject to three increasing trends (World Ocean Assessment, 2017). First, human needs are increasingly met from the ocean, some directly, e.g., food from fisheries, aquaculture and ranching (Ferreria *et al.,* 2017; APEC, 2016), and some indirectly, e.g., greater shipping of commodities in an increasingly globalized world (Simcock & Tamara, 2017; Simcock, 2017). Second, direct drivers affecting the High Seas are expected to increase, including fishing, aquaculture, mining, energy and defence activities, sound pollution from transportation, and chemical and biological pollution from increased use of the sea and coastal living. Third, as efforts to increase the sustainability of ocean uses within national jurisdiction increase (FAO, 2016; CBD, 2017), some of the effort is moving offshore (Merrie *et al.,* 2014; Gjerde *et al.,* 2013). These three trends have major impacts on nature and its contributions to people, including the challenge of managing rapidly emerging industries such as mining, undersea communications and energy. Improving shared governance, mainstreaming nature, and a new High Seas convention are proposed as options.

6.3.3.2.1 Improving shared governance

Supporting and expanding existing conservation cooperation mechanisms represent a promising short-term option for protecting High Seas biodiversity. Some of these institutions are expanding their initiatives into areas beyond national jurisdiction, e.g., through fisheries observer programs, anti-IUU (illegal, unreported and unregulated) fishing measures. Regional organisations, particularly, the Regional Seas Programmes, Regional Fisheries Management Bodies and their conventions, and GEF Large Marine Ecosystems (LME) programmes can also play an important role in combating land-based marine pollution.

A common first step in establishing international coastal cooperation is a transboundary programme of technical cooperation, such as the Regional Seas Programmes and Conventions and the GEF initiated LME projects. Many of these programmes have helped create effective environment agreements among countries.

Territorial disputes may impede conservation, to the extent that in contentious areas, multilateral cooperation has been limited to technical cooperation among a subset of countries rather than active management (Williams, 2013). Where maritime territory disputes remain, countries are urged to settle these through the UNCLOS legal routes. UNCLOS offers four options for dispute settlement and by finding the means that best suits, states have settled many disputes. However, instances where some of the large powers have opted not to resort to UNCLOS dispute settlement system may jeopardize the effectiveness of the forum (Klein, 2014; Gates, 2017).

"Ocean grabbing" is a term used to describe an emerging concern over the dispossession or appropriation of ocean space or resources from prior users, rights holders or inhabitants resulting from governance processes with power asymmetries among participants. More broadly, the issue of accumulation by dispossession is both an issue that can impede conservation and be used by conservation interests to obtain a foothold over community lands (Harvey, 2003; Hall, 2013; Benjaminsen & Bryceson, 2012). If the needs of local communities and ecosystems are not fully taken into account, allocation of access rights to ocean space or resources may undermine human security and impair biodiversity components. Conservation allocations such as marine protected areas, and rights-based approaches such as individual fisheries quotas may be conducted in ways that do not undermine human security and ecological functions (Bennett *et al.,* 2015).

Thinning and disappearing sea ice, melting permafrost, and circumpolar climate change, however locally and regionally varied, are commonly identified as playing their part in rapidly unsettling the geographies of Arctic governance (Overland & Wang, 2013; Smith & Stephenson, 2013; Hussey *et al.,* 2016; Stephenson, 2018). Strategies are being sought that will promote renewed international cooperation and reduce the risks of discord in the Arctic, as the region undergoes new jurisdictional conflicts and increasingly severe clashes over the extraction of natural resources in a region that is critical to the prevision of globally important NCPs (Berkman & Young, 2009; Young, 2010; Keil, 2015; Hussey *et al.,* 2016; Harris *et al.,* 2018).

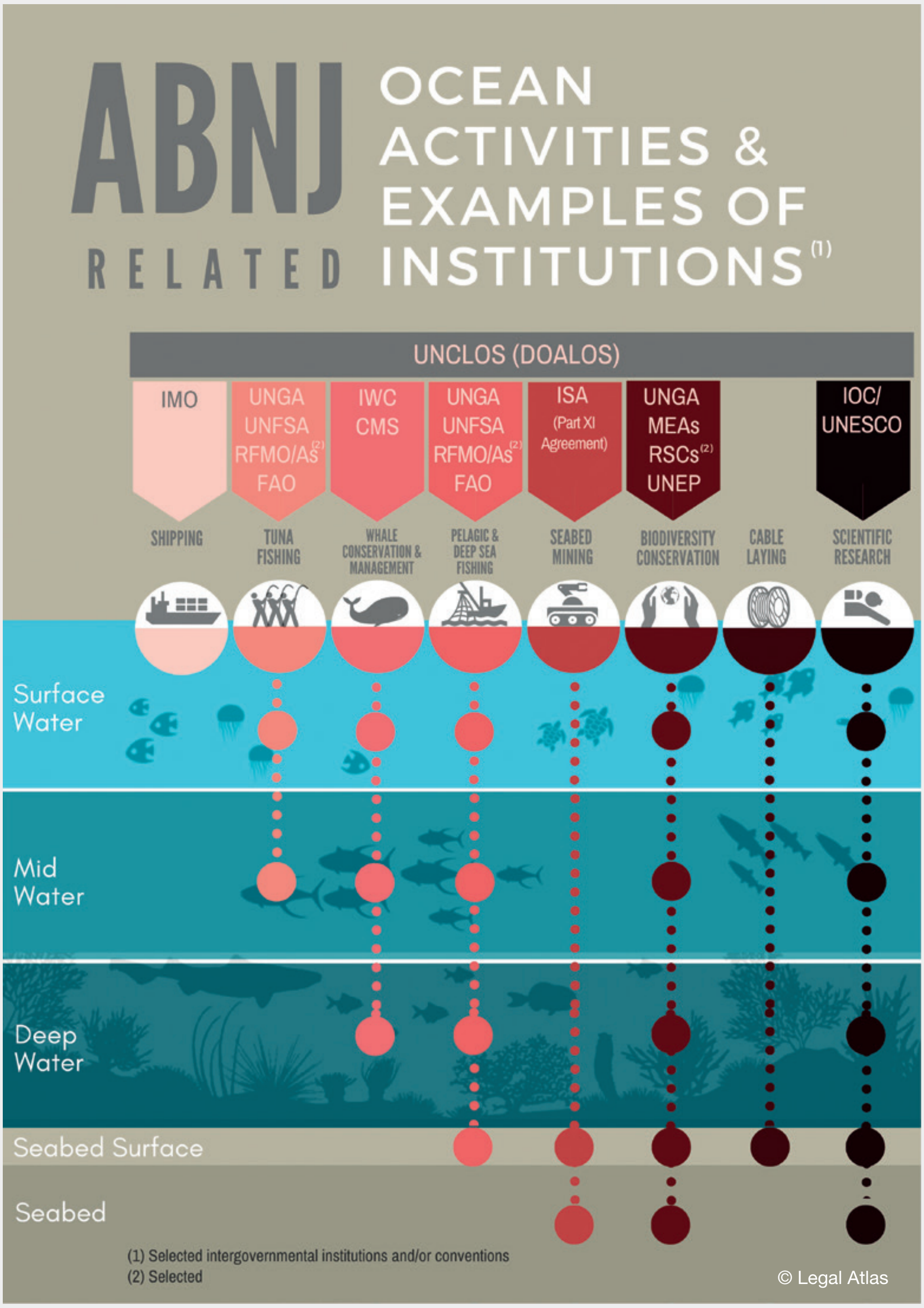

Figure 6 3 **Multiple ocean uses and examples of institutions related to areas beyond national jurisdiction illustrating the different ocean depths relevant to the activities and institutions.**

Source: UNEP-WCMC (2017).

Several organizations have advocated for the negotiation of a harder law regime for the Arctic (Kankaanpää & Young, 2012), including firmer institutional, financial and regulatory foundations for the Arctic Council (Berkman & Young, 2006) and improved transboundary conservation planning (Greenpeace, 2014; Hussey *et al.,* 2016; Edwards & Evans, 2017; Harris *et al.,* 2018).

6.3.3.2.2 Mainstreaming nature and its contributions to people

Recognising the rising pressures on biodiversity on the High Seas, most sectoral regulatory agencies are recognizing the need to mainstream biodiversity conservation into their approaches to policy and management (CBD, 2016). Responding to growing public pressure from NGOs and international agencies, measures are being introduced. For instance, Regional Fisheries Management Organisations (RFMOs) are implementing UNGA Resolution 61/105 to protect deep sea Vulnerable Marine Ecosystems (VMEs) from bottom trawling (Rice *et al.,* 2017). Similarly, sectoral agencies such as the International Seabed Authority for deep-sea mining (Anton, 2011) and International Maritime Organisation for shipping are adopting, or urged to, additional policies and measures to manage and mitigate the pressures of these sectors on High Seas biodiversity and their habitats.

The effectiveness of conservation policies for the High Seas depend crucially on how well they are implemented, a challenge that sectoral regulatory agencies have been grappling with for decades. In some areas, there is a need for substantive scaling up resources and prioritizing areas of rising pressure, e.g., for tuna fisheries (Juan-Jorda *et al.,* 2017). A major obstacle is the lack of priority that countries give to international arrangements for nature conservation. The latter highlight the role of regional management bodies and their secretariats in mobilizing action, and that of NGOs that advocate action through campaigns engaging public attention and presenting submissions to management bodies.

The experience of RFMOs in protecting VMEs from deep sea fishing shows that a strong science foundation is crucial as the knowledge basis (MacDonald *et al.,* 2016), in addition to guidance on suitable conservation management measures (FAO, 2009). As little of the seabed is mapped, however, the knowledge base is generally poor. Protection is still feasible using responsive mechanisms based on existing knowledge, e.g., real-time move-on (cease-fishing) rules triggered when the presence of a VME is identified through bycatch indicator taxa; and great progress on identifying VMEs and Ecologically and Biologically Significant Marine Areas, even with incomplete information (Dunn *et al.,* 2014).

For RFMOs and other sectoral agencies, member States need to provide costly surveillance and enforcement (Rice *et al.,* 2014). These functions present a greater challenge on the High Seas than within national jurisdictions, but additional policy interventions have enhanced the effectiveness of existing policies, e.g., the FAO Port State Measures Agreement (2009, in force 2016) increased the effectiveness of other measures to deter IUU fishing (FAO, 2017). Sectoral management agencies, including fisheries, and NGOs such as Global Fishing Watch, are now testing new technologies such as satellite monitoring of electronic fisheries operations, onboard CCTV monitoring of catch and bycatch, and real-time data entry (Hosken *et al.,* 2016). These technologies can lead to better monitoring, control and surveillance.

Greater efforts are needed to achieve coherence between the efforts of sectoral management agencies and the efforts of biodiversity conservation agencies, including those led by intergovernmental organizations such as the CBD, e.g., program for identifying Ecologically or Biologically Significant Areas (EBSAs – Johnson *et al.,* 2018), and by NGOs, e.g., Birdlife International. In fisheries, poor coherence leads to low returns on conservation and management investments (Garcia *et al.,* 2014a). The obstacles to improving coherence are high because it requires governance processes with convening power to bring the agencies together, the duty to cooperate both in selecting policies and measures that work synergistically and implementation strategies that encourage cooperation (Garcia at al., 2014b).

6.3.3.2.3 Pathways to protect nature in the High Seas

The need for coherence poses the greatest challenge, and greatest opportunity, for changing the trends of loss in High Seas biodiversity. The limitations of UNCLOS to deal effectively with nature conservation in the High Seas biodiversity was recognized over a decade ago. Open Ended Working Groups of the UNGA (http://www.un.org/depts/los/biodiversityworkinggroup/biodiversityworkinggroup.htm) prioritized three themes: the ability to apply spatial management tools, including High Seas Marine Protected Areas (MPA) binding on all marine industry sectors; marine spatial planning across sectoral agencies; access and benefits sharing to marine genetic resources; environment impact assessment, technology transfer and capacity building.

UNGA has initiated in 2017 an intergovernmental conference on an international legally binding instrument under UNCLOS on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (General Assembly Resolution 72/249); with expected conclusion in 2020. These negotiations will be a major factor in the future trajectories of High Seas biodiversity. An eventual future instrument is likely to include provisions for area-based management including MPA, environmental impact assessment and marine genetic resources. National government are encouraged to support the timely agreement of an effective instrument for marine protection and then implement the provisions with regard to key sectors, e.g., fishing, seabed mining, coastal oil and gas, geoengineering and waste disposal.

6.3.3.3 Coastal Waters

National governments play a major role in determining the balance of coastal protection and resource use, and global codes and conventions can help promote national action, e.g., SDG 14 (life below water). Governments face the challenges of harmonising and coordinating responsible agencies and interests, setting national policies and priorities, coordinating and integrating planning, resourcing, implementing, monitoring and reporting. Locally led initiatives can also feed up into national policies (see 6.3.3.3.3).

6.3.3.3.1 Promoting integrated management

Since the 1980s integrated coastal environment management concepts have been a focus of academic attention (Merrie & Olsson, 2014). Conservation, international and national organisations also have promoted, developed and piloted several related forms of integrated marine and coastal management, especially Integrated Coastal Management (ICM) and Sustainable Development in Coastal Areas (ICM/SDCA – http://www.pemsea.org/our-work/integrated-coastal-management/SDCA-framework), MPA, Marine Spatial Planning (MSP) (Ehler & Douvere, 2009) and Ecosystem Based Management (EBM) (Agardy *et al.,* 2011). MSP and MPA illustrate the challenges.

MPA have been applied most commonly to fisheries and special area conservation. Their effectiveness depends on the economic conditions, governance and institutional contexts in which in which they are applied (Agardy *et al.,* 2011; Ban *et al.,* 2013; IPBES, 2018c), their location (Mouillot *et al.,* 2015), and local livelihood activities that are displaced by the MPA must be addressed (Cudney-Bueno *et al.,* 2009; Bennett & Dearden, 2014; IPBES, 2018d).

Conversely, when MPA management incorporates biophysical, economic, and social characteristics of the system, more sustainable fishing practices may result (Cinti *et al.,* 2010; Sciberras *et al.,* 2015; Gill *et al.,* 2017).

MPA and systems of interconnected MPA offer conservation management options for both the short and long term, for governments, private, NGO, and IPLC actors. The social and economic benefits of MPA can improve community well-being via increased income from fisheries or tourism (McCook *et al.,* 2010), and IPLCs can engage in stakeholder processes so that MPA benefit both people and nature (Bennett & Deardan, 2014). The private sector can contribute innovative financing for implementing and enforcing MPA (Theile & Gerber, 2017). Rights-based approaches to MPA management and ocean governance offer a promising option to strengthen MPA and MPA Networks implementation (Bender, 2018). NGOs have an important role to play in implementing MPA, through assisting community engagement and capacity building, monitoring and evaluation, and developing and implementing economic incentives to support MPA (Mascia *et al.,* 2009).

Marine spatial planning (MSP) is a comprehensive "public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objective *that are usually specified through a political process."* (IOC-UNESCO Marine Spatial Planning Programme – http://msp.ioc-unesco.org/). It evolved together with MPA developments (Katsanevakis *et al.,* 2011), bringing together multiple users of the ocean – energy, industry, government, conservation and recreation. Not an end in itself, intent of MSP is a coordinated and sustainable approach to ocean use. Policy-relevant guidebooks have been developed to support implementation (e.g., Ehler & Douve, 2009). Despite good pilot cases and some success, a 2012 review concluded that: "Comprehensive MSP initiatives are relatively new and thus largely untested. In those that are underway, there appears to be greater emphasis on planning than on post-plan implementation" (Secretariat for the CBD and GEF, 2012, p.32). Furthermore, the requirements of cross-sectoral decision-making can be seen by line ministries as onerous and undesirable (Secretariat for the CBD and GEF 2012), although this is clearly very important in implementing the mainstreaming requirements of the CBD. A further challenge is that the adaptable nature of MSP must continually maintain a balance of ecosystem conservation and economic and social aims (Merrie & Olsson, 2014), making frequent updates and adaptive responses necessary. National capacity to implement integrated environmental stewardship can be affected also by the relative powers of the ministries. In some governments, environment ministries are newer and weaker compared to economic and central ministries (Jordan *et al.,* 2010).

Overall, the obstacles to implementation, longer time frame for success, complexity of the integrated solutions, and need to be responsive to changing externalities (e.g., climate change, new trade agreements, changing markets for traditional products, etc.) all mandate that governance arrangements focus also on shorter term responsive action, including sectoral in cases, to address the most immediate problems in a step by step approach. Nevertheless, sectoral or local actions need to be nested with higher level institutions adjudicating on cross-sectoral trade-offs resulting from specific actions, such as those competing for coastal space: ports, urban development, fisheries, tourism, and conservation.

Integrated management at the national and local levels: National governments, pivotal to integrating management across scales and to negotiate international and regional agreements. Typically, an international agreement is the catalyst for national action, however avoiding piecemeal solutions is difficult since local and national levels actors are continuously responding to accelerate social and environmental changes. On the other hand, localized solutions can be effective. For instance, while a global instrument against plastic pollution will take time, national and sub-national actions are contributing to address the problem (Niaounakis 2017). National and state governments, for instance, can impose restrictions on the sale and use of single-use plastic bags, for instance as did Chile in 2017 in restricting such items particularly in coastal villages and towns.

Decentralizing policies to sub-national and local governance have a direct impact on the type of coastal and marine management. In the last three decades, coastal and marine management has been affected by the opportunities and challenges caused by national re-organisations associated with the devolution and decentralisation of government powers to state, province or local government and community levels, requiring rapid capacity building at sub-national levels. In Southeast Asia (e.g., Indonesia, Philippines and Vietnam) devolution models were embraced with varying results. Indonesia has received major World Bank development and conservation support for community and local government-based empowerment, and the local outcomes covered the spectrum from responsible leadership, to elite capture, patronage networks, and outright corruption (Warren & Visser, 2016). Another example of diverse outcomes of local level management is the coastal cities in the Great Buenos Aires conurbation (Argentina), comprising ten different jurisdictions at national, provincial and municipal government level. Responding to local politics and globalization pressures on competitive industries, decades of decentralization or federation efforts were resolved essentially in favour of decentralisation rather than metropolitan integration (Dadon & Oldani, 2017).

Successful short and medium-term sub-national interventions can include small scale actions and projects at sectoral or cross-sectoral level, as for this scale, sectoral boundaries may not be so rigidly delineated. Technical projects, research institutes (as entry points for diagnosis, finding solutions, monitoring status) and community, including youth, engagement, are critical elements to the success of grassroots conservation.

Indigenous Peoples and Local Communities are central to sub-national marine conservation action but vary significantly in terms of their capacities and needs to manage marine resources under different types of pressures. Across the world, the position and contribution of IPLCs to coastal management vary significantly from areas where communities retain full control to various types of mixed arrangements, to complete deprivation of rights. Evidence demonstrates that local customary institutions can be more effective than formal external ones in promoting management. In Indonesia, continuous traditional marine management such as *sasi laut* and *pangalima laut* were more potent and likely to be obeyed than more modern proclamations, e.g., of Marine Protected Areas (Harkes & Novaczek, 2002; Wiadnya *et al.,* 2011). In Sumatra with well-conceived external support, even cases of corrupt devolved authority could be turned around into local community advantage (Warren & Visser, 2016).

6.3.3.3.2 Mainstreaming nature conservation in sectoral management, with an emphasis on fisheries

National resource managers of coastal waters, private sector enterprises, citizens and consumers can all play a role to help prevent environmental damage, including by protecting vulnerable areas, changing damaging manufacturing practices, sensitive land development, waste disposal and consumption patterns. Collectively, these mainstreaming approaches are now being referred to as ecosystem-based approaches to management within specific sectors. Sectoral activities and policy often determine the conservation approaches but focus on components of nature most closely linked to their sectoral activities. For example, fisheries experts have been early to diagnose environmental problems such as fish stock overexploitation and bycatch, but less likely to focus on a seabird colony finding insufficient food because of a fishery harvest. Effective governance is needed to ensure sectors do not prioritize resource uses to a level that risks unsustainable practices.

In addition to risk of overharvesting, the IPBES regional assessments for Africa, the Americas, Asia and Pacific, Europe and Central Asia found that fisheries conservation is threatened also by other external threats, including many types of pollution, habitat destruction for industries and human living space, invasive alien species from sources including ballast water introductions, nutrient driven hypoxia, jelly-fish blooms, and climate change. These problems call for the joint effort of governance institutions from local, to national, and regional, and even global.

Managing the impacts of fishing and fish supply chains to conserve the target stocks and the environment has become a recognized environment priority, e.g., SDG target 14.4 and Aichi target 6. One-third of marine fish stocks (including invertebrates) are fished at biologically unsustainable levels, 60% at sustainable levels, and 7% underfished (FAO, 2018a). However, many marine fish stocks are of unknown status, suggesting that estimates about sustainable fisheries management may be over-optimistic (FAO, 2018a). Positively, there is evidence that stock rebuilding is occurring in countries including USA, Australia, Namibia, Canada, and the European Union (FAO, 2018a). However, evidence on ending overfishing and rebuilding depleted stocks suggests that the successful recovery of depleted marine resources depends possibly more on management of infrastructure and socio-economic contexts than on having accurate stock assessments alone, especially if management measures that are suited to data-poor fish stocks are used (e.g. IPBES, 2018c; Brodziak *et al.,* 2008; Rosenberg *et al.,* 2006; Caddy & Agnew, 2004; Garcia *et al.,* 2018).

Despite evidence for the need to address overexploitation from fishing, many countries and RFMOs have not fully implemented the extensive international legal framework, including both hard and soft law instrument, referred to as the Code of Conduct for Responsible Fisheries and its instruments (FAO, 2012). The World Ocean Assessment (United Nations, 2017) proposed the following options: ending overfishing and rebuilding depleted stocks; eliminating IUU fishing; reducing the broader ecosystem impacts of fishing including habitat modification and effects on the food web; reducing the adverse impacts of pollution; and reducing the adverse impacts of perverse subsidies.

A major challenge is that the options are highly context specific and need to be purpose built, albeit lessons can be learned from practice elsewhere and locally specific solutions involve opportunities for co-management. Developed countries may use complex, data rich ecological-economic models (Nielsen *et al.,* 2018), but the models, management institutions and methods, e.g., catch shares, individual transferable quotas (ITQs), may not suit developing country and small-scale fisheries. Specific cultural and ecological contexts are important for successful community-based fisheries management, making any model hard to upscale (Poepoe *et al.,* 2007), although local leaders, social capital and incentives were found to be important (Gutiérrez *et al.,* 2011).

Communities making a living from small-scale fishing and coastal resources have often been ignored in national and international policy, despite their strong dependency on the resources (García-Quijano *et al.,* 2015). Furthermore, assessments, including the present one, generally neglect to consider women's role in this sector and thereby ignore major unrecorded fish catches (Gopal *et al.,* 2017). As well as women, policies need to consider the rights and concerns of Indigenous Peoples with respect to livelihoods, equity and rights, participating and contributing knowledge to fisheries and coastal ecosystem management (Capistrano & Charles, 2012; Fisher *et al.,* 2015). The 2015 Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (SSF-VG) were developed to overcome the neglect of local communities, indigenous and non-indigenous. Countries are encouraged to implement the SSF-VG, which incorporates comprehensive environmental as well as human rights and equity principles.

"Balanced harvest" (Garcia *et al.,* 2016) has been debated as a possible approach to increase food from the sea while maintaining sustainable fisheries but evidence on its effectiveness is lacking as it has not yet been implemented.

To address sustainability through eliminating IUU fishing, countries and Regional Fishery Bodies should not only exercise effective fisheries management, but also implement strong surveillance capacities, e.g., Petrossian, 2015, (see 6.3.3.2.1 and 6.3.3.1.1) and adequately invest in research and technical capacity, for instance improving recognition of illegal landing species and sizes (e.g., Romeo *et al.,* 2014).

Customized options to reduce and eliminate bycatch and discards are essential to minimize ecosystem impacts of fishing (Hall *et al.,* 2017; Gladics *et al.,* 2017; Gilman *et al.,* 2016, Little *et al.,* 2015; Broadhurst *et al.,* 2012). National measures to reduce the direct impacts of fishing on marine mammals, sea turtles and seabirds have proven successful (Grafton *et al.,* 2010). In fisheries for migratory species and in remote ocean areas like those in the Southern Ocean, international inter-organizational collaboration is needed (Osterblom & Bodin, 2012). In addition to managing bycatch and discards, reducing the broader ecosystem impacts of fishing depends on establishing new and implementing current MPA, and restoring critically endangered ecosystems (e.g., Kennelly & Broadhurst, 2002; Fourzai *et al.,* 2012). Adoption of the ecosystem approach to fisheries across countries has, according to FAO, been slow but has consistently moved forward (FAO, 2018b).

Fishery subsidy reforms, which includes elimination of harmful subsidies, decoupling subsidies from fishing effort, re-orienting subsidies to management and technological improvements, conditioning subsidies on fishery performance, and substitution of ongoing subsides for buyback schemes (Cisneros-Montemayor, 2016; Tipping, 2016) are innovative attempts to redress current failures in the interest of resource protection and sustainability.

Seafood certification and ecolabelling are economic instruments designed to change consumer seafood demand for well-defined target species or fisheries whose sustainability is under threat, direct them to better environmental choices, create market access, and provide incentives to improve fishing practices through price premiums to producers (FAO 2018b). The uptake of these schemes has been much greater in developed countries and is considered to have had the most important non-State positive impact on fisheries sustainability, but more efforts are needed to increase its uptake and the lower barriers to entry for developing country and small-scale fisheries (Gutierriz *et al.,* 2016; FAO, 2018b). In view of the diversity of ecolabelling and certification schemes have developed, for which FAO has established a Global Benchmark Tool. To date, only three fisheries and one aquaculture scheme have been benchmarked. Several schemes are now addressing social standards but as yet these lack agreed performance norms (FAO, 2018b). As precursors to certification, fisheries improvement programs (FIPs) are important stepping stones towards sustainability (https://fisheryprogress.org/).

Certification and ecolabelling have had a major positive impact on improving fisheries sustainability and, for developed counties, may be the most important recent non-government fisheries management initiative. Evidence shows that support of governments and other fisheries actors are essential for fisheries certification (Gutierrez *et al.,* 2016). Controversy over certificate standards and questions over accountability for the certification machinery and decisions have arisen (Miller & Bush, 2015; Gulbrandson & Auld, 2016). In addition, certification has had only modest success so far in including developing countries and small-scale fishers and producers. A further challenge is that only some consumers are yet willing to pay more for certified seafood (FAO, 2018b).

6.3.3.3.3 Scaling up from sub-national project pilots

National agencies, including government science and management agencies, play key roles identifying, diagnosing, researching and developing technical projects and pilots on marine biodiversity conservation, often following specific sub-national cases, such as Australian efforts to sustainably manage competing uses of the Great Barrier Reef Marine Park (Merrie & Olsson (2014).

Scaling up is the challenge for sub-national initiatives. In Asia, the PEMSEA partnership has demonstrated the feasibility of building on small scale local success. For example, in Batangas, Philippines, efforts spread from five local authorities to 34, covering the watershed and coastal areas of the whole province (http://www.pemsea.org/our-work/integrated-coastal-management/ICM-sites). By 2021, ICM is expected to reach 25% of the East Asia region's coastline using the PEMSEA model that has performed well in East Asia, as national governments collaborate towards a regional strategy. The work starts at the local government level, rather than relying on national policy to initiate action. Like other integrated approached, ICM relies on networks of experts reaching out to interested local actors, having also attracted attention from international donors.

Successful examples of local governance, albeit with external support in most cases, are described in the IPBES regional assessments. For instance, since 2005 in the Pacific region, locally managed marine areas have grown in number; in Madagascar, the NGO Blue Ventures is piloting payment schemes for blue carbon; and in West Africa, mangrove conservation has progressed in a six-country development project with local partners.

6.3.3.3.4 Building ecological functionality into coastal infrastructure

Given the inevitability of future coastal infrastructure development, it is vital that decision makers consider the ecological functions of coastal ecosystems from the start (Daffron *et al.,* 2015). Altered and damaged ecosystems are difficult to restore or rehabilitate, or not politically or economically feasible. Maintaining and managing natural system by removing stressors such as pollutants may be a fraction of the costs of restoration (Elliot *et al.*, 2007). In some cases, however, created ecosystems may even be culturally preferred. With the rapid increase in created coastlines, especially around urban areas, ecosystem rehabilitation, increasing attention has been paid to remediation and multi-purposing coastal structures such as breakwaters and marinas.

6.3.3.3.5 Engaging NGOs, industry and scientists as stakeholders to achieve common ecological and social good outcomes

Across countries, interpretations and awareness of the importance of conserving nature and its contributions to people in the oceans are diverse and dynamic, although a growing degree of convergence is emerging as a result of local social movements, global environment conventions and agreements, scientific efforts, and environmental advocacy. New national and local environmental NGO are emerging, creating greater and more distributed demands for conservation action. For instance, large international NGO have set up national branches and joint ventures in many countries, bringing their own concepts and values and adapting them to local circumstances and channels of influence. Although the translations do not always work, with time and experience, the short-term actions can mature to more appropriate forms for local ecosystems and species, values and knowledge, e.g., national versions of seafood consumption guides.

Powerful industry players may obstruct and even capture the political processes, e.g., port infrastructure, shipping, industrial fishing, tourism and real estate (Jenkins & Schröder, 2013; Bavinck *et al.*, 2017), but industry actors are also highly relevant to finding solutions. Options to involve private interests include corporate social responsibility, market-based instruments such as certification (e.g., seafood certification, 6.3.3.3.2) and best practice in fisheries and aquaculture production methods (Jenkins & Schröder, 2013). In the case of coastal hypoxia caused by nutrient loading, more attention is needed to engage sectors responsible for the largest point-source nutrient emissions (farmers, intensive livestock producers, agricultural chemical and fertilizers companies) in policy decision-making, remedial action, educational programmes and training sessions (STAP, 2011).

Marine assessment processes provide opportunities for management agencies, research institutes, NGO and other citizen groups to assess and report the status of nature and its contributions to people, to identify issues and suggest solutions. International collaboration on assessments and standards can enable national status reports to be shared and information to be aggregated and compared regionally and globally. In addition to international government organization assessments, such as the World Ocean Assessment, NGO and privately funded systems can contribute to collaborative efforts such as the Ocean Health Index (http://www.oceanhealthindex.org/).

6.3.4 Integrated Approaches for Sustainable Freshwater

Freshwater ecosystems include rivers, lakes, reservoirs, wetlands and groundwater systems. The options for decision makers discussed under this section are based on SDG6 (clean water and sanitation) and several Aichi Biodiversity Targets (ABTs). Population growth, climate change, increasing demand for water, institutional policies, and land-use change – all interact to determine available water supply and use (Liu *et al.*, 2013). Short and long-term options to manage water need integrated and adaptive governance that reduce pressures on water, encourage nature-based solutions and green infrastructure, and promote integrated water resource management as well as considerations of water-energy-food nexus (WWAP/UN-Water, 2018). Adaptive measures include rainwater harvesting, improved pasture management, water reuse, desalinations and more efficient management of soil and irrigation water, among others (Jiménez *et al.,* 2014). Inclusive and informed approaches to water governance open up opportunities for stakeholders with diverse interests to be involved in making decisions that are integrated, adaptive, resilient, innovative and responsive (WWAP, 2018; Ison & Wallis, 2017; Razzaque, 2009; Pahl-Wostl, 2007). Transformational change requires a move away from the business as usual approach and puts emphasis on the recognition and integration of multiple values, including intrinsic and relational values, in water management (WWAP/UN-Water, 2018; Bartel *et al.,* 2018).

The complexity of water resources is reflected in its status as an economic good as well as a public good (CESCR, 2003; Griffin *et al.,* 2013; Whittington *et al.,* 2013). It is well established that challenges to water management are aggravated as there are ambiguities in relation to the status and scope of legal rights governing access to water (McCaffrey, 2016; Murthy, 2013). It is critical to understand the combination of options and instruments that can be designed to meet policy objectives and allocations arrangements (WWAP, 2015; OECD, 2015). In the short-term, a clear legal status needs to be in place for all types of water, such as surface water, groundwater and wastewater along with a clear indication of the ownership and user rights and polluter duties. Such a legal regime will enable the responsible authority/ies to determine the level of access to be given to various users, monitor the losses in water distribution, impose sanctions such as fines or penalties, and determine the response measures in cases of exceptional circumstance, such as drought and severe pollution (Ring *et al.,* 2018; Acosta *et al.,* 2018; Stringer *et al.,* 2018; Scarano *et al.,* 2018; WWAP, 2015).

In many countries, environmental flow allocations continue to be used as a surrogate for the protection of Indigenous Peoples and Local Communities' interests in water management (e.g., NWI, 2004; DoW, 2006), with little or no consideration for IPLC customary rights of freshwater resources in water allocation decisions (Finn & Jackson, 2011; Bark *et al.,* 2012; Jiménez *et al.,* 2015). Low representation of IPLCs in water resource decision-making has often led to conflicts and disagreements over values and management priorities, which have often been aggravated by clashes between market-based instruments and local customary rights (Boelens & Doornbos, 2001; Boelens & Hoogendam, 2001; Trawick, 2003; Jiménez *et al.,* 2015) (Also see Supplementary Materials 6.3).

This section presents both short and long-term options for decision makers that contribute to integrated approaches to freshwater governance **(Table 6.5)**.

6.3.4.1 Improving water quality

***Setting clear water quality standards*:** Improved water quality standards are essential to protect both nature and human health, by eliminating, minimizing and significantly reducing different streams of pollution into water bodies (SDG6) including river basins **(Figure 6.4)**. Command and control regulations such as end-of-pipe control, quality standards and discharge permits have a significant role to play to reduce point source pollution (e.g., wastewater from households, commercial establishments and industries) (Kubota & Yoshiteru, 2010; UNEP, 2016; OECD, 2017; WWAP, 2017; WWAP, 2012). A strong and transparent implementing authority with necessary technical and managerial capacity as well as provisions on access to information that benefits implementation and enforcement processes would benefit such regulatory measure (UN-Water 2015b). In addition, mitigation of the impacts of pollution from non-point or diffuse sources (e.g., run-off from urban and agricultural land) requires ecological responses,

Table 6 5 **Options for integrated approaches for freshwater governance.**

Short-term options	Long-term options	Key obstacles, potential risks, spill-over, unintended consequences, trade offs	Major decision maker(s)	Main level(s) of governance	Main targeted indirect driver(s)
Improving water quality					
Setting clear water quality standards; data gathering & monitoring		• Identification of non-point sources • Lack of managerial and technical capacity	National sub-national and local government, private sector, IPLCs, civil society	National, sub-national, local	Institutions, governance, technological
Collaborative initiatives and IPLC monitoring		• Lack of adequate monitoring; • Lack of adequate or effective remedial action	Global, regional, national government, private sector, IPLCs, civil society, donor agencies, science and education organisations	All	Institutions, governance
Technological advances		• Lack of quality standards • Lack of institutional and financial capacity	Regional, national government, private sector, donor agencies, science and education organisations	All	Economic, technological
Strengthening standards for corporate sector		• Lack of compliance monitoring • Lack of enforcement	Global, regional, national government, private sector, donor agencies, NGOs	All	Economic, institutions, governance
Managing water scarcity					
Water abstraction charge		• Abstraction charge may not reflect the environmental cost and vulnerability of local population	National sub-national, local government; IPLCs, private sector, citizens (households, consumers), community groups, farmers	National, sub-national, local	Institutions, economic, governance, demographic
Restrict groundwater abstraction		• Lack of management plan for groundwater • Lack of (or weak) ownership right of groundwater • Lack of monitoring of data • Lack of policies harmonising groundwater with energy, agriculture and urban development policies	National, sub-national, local, private sector, IPLCs, citizens (households, consumers), community groups, farmers	National, sub-national, local	Economic, institutions, governance. demographic
Water efficient agricultural practices		• Lack of access to water efficient technologies for agriculture and optimized irrigation systems • Lack of technical assistance and finance	National, sub-national, local, private sector, farmers, IPLCs	National, sub-national, local	Technological, institutions, governance, economic
Engaging stakeholders					
Integrated, rights based, and participatory approach to water management		• Weak (or lack of) transparent process to identify relevant stakeholders • Weak provisions to access information by stakeholders • Ineffective participation of all stakeholders including IPLCs • Weak (or lack of) a right based approach to protect water resource • Inadequate regulatory framework to support custodianship and open access	National, sub-national, local government; private sector, civil society, IPLCs, donor agencies, science and education organisations	National, sub-national, local	Institutions, governance, cultural

Short-term options	Long-term options	Key obstacles, potential risks, spill-over, unintended consequences, trade offs	Major decision maker(s)	Main level(s) of governance	Main targeted indirect driver(s)
Use of economic instruments					
Payment for water ecosystem services		• Lack of quantifiable environmental objectives at the watershed level • Lack of evaluation of environmental additionality • Lack of monitoring of ecosystem services outcomes	National, sub-national, local government, civil society, IPLCs, private sectors, donor agencies	National, sub-national, local	Economic, institutions, governance
Improving investment and financing					
Public private partnership		• Ineffective regulation, monitoring • Lack of consideration of ILK and IPLC cultural values	National and local governments; civil society including communities, small farmers, workers, women, and IPLCs. Agribusiness, mining companies, finance capital, and international financial institutions	All	Economic, institutions, governance
Promoting Integrated Water Resource Management					
Fostering polycentric governance		• Fragmentation of instruments and institutions • Complexity of issues • Reluctance to move beyond traditional methods	National and local governments, IPLCs, Civil Society, private sectors	Regional, national, sub-national, local	Economic, governance, institutions
Facilitating integration across sectors		• Acknowledge water-food-energy nexus • Broadening the knowledge base	National and local governments, IPLCs, Civil Society, private sectors	Regional, national, sub-national, local	Economic, governance, institutions, technological
Harness international normative framework		• Lack of compliance and implementation	National and sub-national government	Regional, national, sub-national, local	Economic, governance, institutions
Encouraging transboundary water management					
Implementing international law norms and basin treaties		• Lack of political will • Fragmentation • Lack of funding • Lack of implementing mechanisms and institutions	• Treaty Secretariats • National and Supra-national governments • Non-state actors such as NGOs, private sectors, individuals	Global, international, national	Economic, institutions, governance, regional conflicts
Addressing fragmentation		• Lack of political will • Lack of implementing institutions	Treaty secretariats, National supra-national governments	Global, regional, national	Governance, institutions
Strengthening participatory tools		• Lack of information • Lack of effective consultation and participation; • Weak institutions to promote co-decisions • Lack of monitoring	Treaty secretariats, national and supra-national governments	Global, regional, national	Governance, institutions

and education and awareness programmes (OECD, 2017). A basin wide programme can play a positive role in reducing run-off from agriculture (UNEP 2016; GEO6 Freshwater). Moreover, nature-based measures on water purification, soil erosion, urban stormwater run-off, flood control can effectively promote green infrastructure (WWAP/UN Water 2018; Also see section 6.3.5.3).

***Collaborative initiatives*:** The countries with shared water may develop and enforce water quality standards through international or inter-state agreements (GEO-6 Freshwater, 2017). Agreements managing transboundary water can identify highly contaminated sites, develop and implement remedial action and monitoring, and contribute to measurable improvements in the water quality (GEO-6,

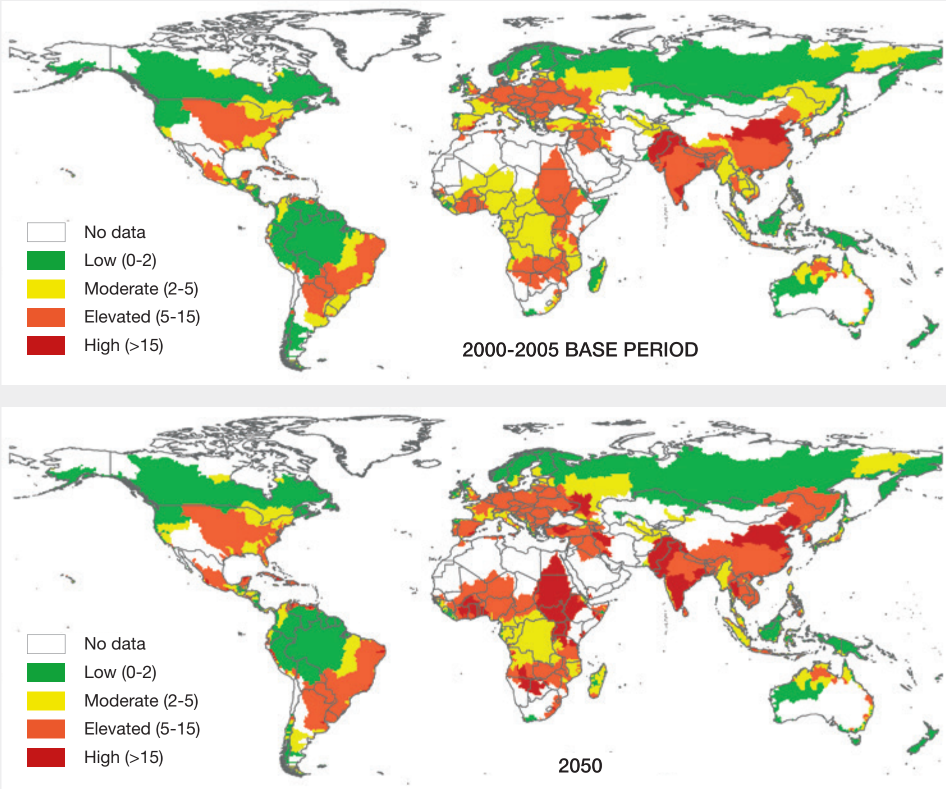

Figure 6 4 **Water quality risk indices for major river basins.**

Water quality risk indices for major river basins during the base period (2000-2005) compared to 2050 (Veolia & IPFRI, 2015, fig.3, p.9).

Freshwater; UNEP, 2016). Well-defined and collaborative international commissions (e.g., Rhine Action programme) or national institutions (e.g., London River Action Plan, 2009) can reduce fragmentation of water management and provide a valuable platform for all relevant actors within the river basin (UNEP, 2016). Such international (e.g., Danube river, Black Sea) and national as well as local collaboration (e.g., 'River Chief' system in China, Wang *et al.,* 2017) to set water quality standards can help ensure that financial resources are spent in the most effective way (UNEP, 2016; WWAP, 2017).

IPLC monitoring: The intimate connection that IPLCs maintain with their freshwater bodies, through intergenerational transmission of knowledge and practices, puts them in a privileged position to closely monitor water quality (Sardarli, 2013; Bradford *et al.,* 2017; see chapter 2.2). In many IPLC worldviews, water is a spiritual resource (e.g., the lifeblood of Mother Earth) that must be respected and kept clean (Mascarenhas, 2007; Collings, 2012; Basdeo & Bharadwaj, 2013; Weir *et al.,* 2013; Morrison *et al.,* 2015). Given that pollution poses important threats to many IPLC livelihoods and cultures (e.g., Orta-Martínez *et al.,* 2007, 2017; Kelly *et al.,* 2010; Harper *et al.,* 2011; Huseman & Short,2012; Nilsson *et al.,* 2013; Jiménez *et al.,* 2015; Bradford *et al.,* 2017) different IPLC groups are engaging, or even initiating community-based monitoring of freshwater quality (Deutsch *et al.,* 2001; Benyei *et al.,* 2017), although evidence on the effectiveness of these initiatives is still largely lacking.

***Technological advances*:** Options targeting the treatment of wastewater and water reuse include pollution prevention at the source (e.g., industries, agriculture), treatment of polluted water, safe reuse of wastewater, and the restoration and protection of ecosystems (UNEP, 2016; WWAP, 2017; WWAP, 2012). The discharge of untreated wastewater can have severe impacts on human and environmental health, including outbreaks of food-, water- and vector-borne diseases, as well as pollution and the loss of biological diversity and ecosystem services (WWAP, 2017). The collection of wastewater and applying appropriate levels of treatment for other uses or discharge into the environment can be improved with quality standards and regulations for incoming wastewater streams and outgoing treated wastewater (WWAP, 2017; OECD, 2017). In addition, it is well established that sufficient institutional capacity and financing are required to build wastewater treatment plants in developing countries and emerging markets (WWAP, 2017).

Data gathering and monitoring: Although there are attempts to gather water related global monitoring data (WWAP, 2017; WWAP, 2012), it is well established that there is a lack of data relating to water quality and wastewater management, particularly in developing countries (UN-Water 2015a) and most notably, in areas inhabited by IPLCs (Nilson *et al.,* 2013; Bradford *et al.,* 2017). Policies that promote holistic assessment of water including gathering of data on water quality and cycle can inform decision-making and increase understanding on how to manage water and ecosystem services sustainably (UNEP, 2016; WWAP, 2012; WWAP, 2015).

Strengthening standards for the corporate sector: There will always be trade-offs between business needs and targets. Better understanding is needed between long-term approaches to meet global goals and short-term approaches chosen by companies. There is opportunity to develop and strengthen voluntary standards that comply with international best practices (e.g., CEO Water Mandate's Integrity Guidelines and Framework, International Water Stewardship Standard, European Water Stewardship Standard), IFC Performance Standards on Environmental and Social Sustainability and SDG6. These voluntary standards aim to enable business and their supply chains to comply with the voluntary standards. Recently, the global corporate reporting standards for water have been revised to measure water consumption and withdrawal in water stressed areas more efficiently (GRI 303: Water, 2018). Such reporting standards aim to enable the corporate decision makers to assess the impacts of their activities on water and how to sustainably manage the resource. Increasing trade of 'virtual water' has led to competition with local water users and exacerbated the need for inclusive and informed water governance (Sojamo *et al.* 2012; Sojamo & Archer 2012). Indeed, several certification schemes include water use and water pollution related issues (e.g., GlobalGap, MPS-ABC, the Rainforest Alliance, IFOAM, Alliance for Water Stewardship). These certification schemes are not without criticisms such as lack of transparency, exclusion of stakeholders, negligible environmental benefits, and poor monitoring. The challenge is to ensure that the certification schemes do not create unequal allocation of water between export-oriented companies and local water users' communities and respect local and customary water rights.

6.3.4.2 Managing water scarcity

Water scarcity is common throughout West Asia and Asia Pacific regions, and in arid parts of Africa and the Americas (GEO-6 Freshwater, 2017). Water scarcity leads to droughts, soil degradation, excessive extraction of groundwater and loss of wetlands with negative impacts on nature and NCP (WWAP/UN Water, 2018; CBD, 2015; Wetlands International, 2010). In the short-term, one option for policy makers is to put water rationing measures to reduce freshwater usage. Water authorities and government may decide to promote water rationing as an emergency measure or as part of a legal water right (GEO6 Freshwater 2017). Option such as water abstraction charge (or water resource management charges) commonly targets industrial users, agriculture, hydropower producers, domestic users and energy production (OECD, 2015), but the charges may not lower water consumption (Finney, 2013; Kraemer, 2003a). To mitigate the negative impacts of any water allocation reform, the decision makers may need to find a balance among divergent interests (Finney, 2013; Rogers, 2002). Abstraction charges for large scale usage of surface and groundwater can be an option to allocate and use water more efficiently. However, such abstraction charge needs to reflect the environmental cost and vulnerability of the local population (Finney, 2013; OECD, 2017b; Kraemer *et al.,* 2003a).

In addition, coherent policy across sectors such as water, energy, climate change and agriculture is needed so that policy reform in one sector does not encourage over-consumption of water resources (FAO, 2014; Bazilian *et al.,* 2011; Olsson, 2013; Benson *et al.,* 2015). In the short-term, e.g., modifications in the land use policy may encourage conservation of water through the use of water efficient agricultural practices, optimized irrigation systems, improved crop varieties, rainwater harvesting and floodwater storage, and discourage agricultural runoff and water loss in the regions with water scarcity (Reddy *et al.,* 2018; OECD, 2015). Greater policy coherence will play a crucial role to reduce negative economic, social and environmental externalities; however, such coherence is vital for better coordination among decision makers and increased collaboration among stakeholders (Rasul, 2016; FAO, 2014; Hussey & Pittock, 2012; Benson *et al.,* 2015).

Option such as desalination of water is used in arid west Asian countries and US (e.g., California) and resulted in increased investment in new desalinization plants (West Asia Regional GEO-6, 2017; North America GEO-6, 2017). Solar desalinization is an alternative that is being applied in several small island states (GEO-6 Freshwater, 2017). There are trade-offs involved as desalination projects require large amounts of energy and 'produces highly concentrated brine' (OECD, 2017) which can negatively affect coastal ecosystems (WWAP, 2017). Thus, the efficiency of the desalinization projects is contested and inconclusive.

Restrict groundwater abstraction: Groundwater abstraction has risen sharply over the last 50 years (Shah *et al.,* 2007) and groundwater pollution has degraded groundwater dependent ecosystems (FAO, 2016a, b; Wada, 2010; Foster, 2013). Surface water and groundwater are closely linked and should be managed conjunctively

(Foster, 2011). It is well established that there is a need for better data regarding existing groundwater resources including their recharge, use and discharge rates (UNEP, 2012; Pandey *et al.,* 2011). As for options, *first*, in the short-term, a management plan on groundwater or both surface and groundwater may clearly set out a framework for groundwater allocation and may contain water quality and salinity management plan (OECD, 2017b; OECD, 2015). *Second*, another short-term approach would be to adopt the rights-based approach to manage water (including groundwater) that may strengthen the provisions on ownership of water, user rights and customary rights, rules related to pollution control and roles and responsibilities of competent authorities (WWAP, 2015; Winkler, 2012; Misiedjan & Gupta, 2014; Mechlem *et al.*, 2016). *Third*, collection and monitoring of data are even more crucial for groundwater management due to the interconnected nature of surface and groundwater and the need for monitoring groundwater abstraction is well established (Custodio, 2002; Konikow, 2005; Shah *et al.,* 2000; FAO, 2016). However, such monitoring will require installation of water meter and tracking of water usage and consumption and monitoring aquifers is technologically demanding and costly (OECD, 2017b; Van Geer, 2006). *Fourth*, groundwater allocation needs to be coherent with policies in other sectors such as energy, agriculture and urban development so that subsidies in one sector do not lead to overconsumption of groundwater (Varady, 2016; Hussey & Pittock, 2012; Alley *et al.,* 2016).

6.3.4.3 Engaging stakeholders

Engagement of stakeholder includes integrated and participatory approach to freshwater management and helps the decision makers to identify innovative and equitable solutions (Varady, 2016). For river basins and water catchments management, multi-level collaborations of government bodies, multi-stakeholder engagement and partnership of various water users at the local level remain crucial (Megdal *et al.,* 2017). Instead of 'top down' policies, it is well established that 'bottom up' policies connecting decision makers and water users promote informed decisions, enhance effectiveness of decisions, and reduce conflicts among water users (Varady, 2016; UNEP, 2016; WWAP, 2017). For example, comprehensive treatment of wastewater is generally undertaken at the local level. Therefore, stakeholder engagement (e.g., through communication, consultation, participation, representation, partnership, co-decision) and motivation for compliance remain crucial for any local policy measure (Akhmouch & Clavreul, 2016). In addition, any such local measure will need to be adapted to economic inequalities, local circumstances, ecosystem needs, competing uses of water and culturally acceptable practices (WWAP, 2017). To increase the use of treated wastewater at the national level, quality standards along with financial or legal incentives can be integrated into national water supply schemes (WWAP, 2017; Hanjra *et al.,* 2015). Consulting with various water users and engaging them in monitoring and performance assessment can help the decision makers to decide the preferred reform options for water management, recognise multiple values and gain a better understanding of the preferences of different waters users (Megdal *et al.,* 2017).

Greater engagement of IPLCs in water governing bodies such as through negotiated agreements (Jackson & Barber, 2015) can serve a purpose in incorporating IPLC social, spiritual and customary values in water management (King & Brown, 2010; Finn & Jackson, 2011; Barber & Jackson, 2012), as well as local ecological knowledge (Weir *et al.,* 2013; Escott *et al.,* 2015). For example, native title law in Australia recognizes Aboriginal rights and cultural values of water, requiring environmental flow requirements for indigenous values in water plans (Jackson & Morrison, 2004; Jackson & Langton, 2011; Jackson *et al.,* 2014). More specifically, adaptive water management regimes have been shown to be effective in accommodating IPLC water entitlements and greater participation of IPLCs in multi-stakeholder water governance (Bark *et al.,* 2012), which may include greater roles of IPLCs in market-based water trading and management mechanisms, where they currently play a minor role (Jackson & Langton, 2011).

Non-governmental organisations can play a role in the formulation of river trusts to protect certain species or pollution event and manage the water catchment (e.g., Severn Rivers Trust in the UK). Success of this type of arrangement depends on the voluntary participation of communities to reach local solutions. Such trust, as a custodian of the waterways, can work with its partners and volunteers to look after the heritage and wildlife on the canals and rivers for present and future generations (e.g., UK Canal and River Trust, 2015).

Along these lines, there is a growing trend towards the recognition of the rights of rivers, as part of a broader movement promoting the rights of nature (Pacheco, 2014; Akchurin, 2015; Díaz *et al.,* 2015; Borràs, 2016; Demos, 2015; Humphreys, 2016). For instance, by granting legal personality to the Whanganui River, the Government of New Zealand found an innovative way to honor and respect the Maori traditional worldviews that see the river as "an indivisible and living whole", as well as the its associated traditional customary institutions for river governance (*Te Awa Tupua (Whanganui River Claims Settlement Act,* 2017; Archer, 2013; Strack, 2017). The legislation recognizes the river as a "living entity" and establishes a co-management regime for collaborative water governance with the Whanganui River Iwi, an indigenous community with cultural ties to the river (Hutchison, 2014; Tanasescu, 2015).

6.3.4.4 Use of economic instruments

There are a range of economic instruments that guide the water sector including tradeable quotas, abstraction charges, payment for ecosystem services (PES), license fees, biodiversity offsets, and subsidies (UNEP 2007; Grafton 2011).

Currently*,* Latin America is the region that counts with more cases of implementation of PES dealing with the protection of watershed services (Brauman *et al.*, 2007; Brouwer *et al.*, 2011; Grima *et al.*, 2017; Martin-Ortega 2013; Stanton *et al.*, 2010). State-led programs constitute the majority of these schemes. Studies assessing the effects of the PES on water flows or quality are basically non-existent, in part due to the methodological difficulties and costs that entail to carry out such type of analyses (Alam 2018; Salzman 2018). Most of PES dealing with water-related ecosystem services are based on empirically untested assumptions about the relationship between land use and the condition and flow of water resources. However, such relationships are complex, and generalizations are difficult to hold (Scott *et al.*, 2004; Sun *et al.*, 2017). Reviews on PES in watersheds have found that most of them are unable to demonstrate impacts on water-related ecosystem services (Brouwer *et al.*, 2011; Yan *et al.*, 2018). In general, the lack of evaluation of environmental additionality is a pervasive problem in PES (Pattanayak *et al.*, 2010), though there have been recent advancements (Jayachandran *et al.*, 2017). The lack of enforcement of conditionality, monitoring of ecosystem services outcomes and evaluation of impacts are reported as recurrent caveats of PES design (Ezzine-de-Blas *et al.*, 2016).

Considerable knowledge gaps still remain with regards to several subjects in PES schemes implemented in watersheds: (a) How to address the uncertainties associated with the relationship between land use and the provision of hydrological services; (b) The extent to which PES schemes are inducing additional effects not only in land use practices but also on the conditions of water resources; (c) How different payment modalities influence rules about the management of common pool resources, such as water; and (d) The long-term relational and behavioural implications of the payments among the involved stakeholders, particularly relations between agents along the watersheds. In addition, the next generation of studies should pay more attention to how to deal with the trade-offs that arise between pursuing ideal design principles, on one hand, and transaction costs and the need to reconcile different policy goals, on the other. Attention should be also given to the profile of PES participants, which has important implications for impact assessment (Grillos 2017; Jack & Jayachandran 2018).

Since the effects of PES schemes on water-related ecosystem services remain largely uncertain, the issue of what can decision makers do to make these interventions effective remain a critical one. *First*, as stated above, impact evaluation systems (and their costs) should be considered in the design of schemes. The establishment of an impact evaluation system should be considered as an inherent part of PES design. Win-win outcomes from PES should not be taken for granted. Indeed, over-reliance on payments as win-win solutions may lead to disappointed results (Muradian *et al.*, 2013). *Second*, in order to enhance legitimacy, the possibility of the existence of multiple values should be acknowledged in the design, implementation and evaluation of PES schemes. The socioeconomic outcomes of the payments might have different meanings to different social groups. *Third*, the assumptions about the relationship between land use and the provision water-related ecosystem services should be derived from empirical evidence. *Fourth*, the management of the scheme should follow adaptive and dynamic principles, based on knowledge generation and incorporation into the design and implementation. Any social-ecological system is dynamic, and the effectiveness of interventions is dependent on the capacity of managers to follow and be responsive to changes.

6.3.4.5 Improving investment and financing

The targets of SDG 6 and the related Aichi Biodiversity Targets (2, 7, 8, 11, 14, 15) require investment in hard infrastructure, such as water- and wastewater- treatment plants, reservoirs, pipes, and sewers; and investment in service systems, including enforceable legal rights, democratic accountability, research and support for local communities and small farmers. The key decision makers for these public goods can be categorized as (A) national and local governments elected by the people of the country; (B) organisations including indigenous and local communities, small farmers, workers, women, and ethnic groups. In parallel there are others pursuing private or market goods, including (C) agribusiness, mining companies, finance capital, and international financial institutions. There are conflicts of interest between these groups in relation to choices for financing investment.

It is well established that investment in wastewater treatment needs to be combined with regulation, monitoring and enforcement (WWAP 2017; OECD 2017a). Leaving ownership and investment to market mechanisms leads to land and water 'grabs', (Woodhouse 2012; Mehta *et al.* 2013), and to price hikes for water and sanitation services (Chong *et al.*, 2006). Thus, business and international financial institutions (group C) have advocated the use of private finance, reinforced by international public sector agencies, to select suitable projects for commercial viability, with public benefits emerging as externalities (Serageldin 1995; Marin 2009; McKinsey 2009). This includes the consistent promotion of Public Private Partnerships (PPPs) as a vehicle for financing investment required for the SDG. PPPs can help incentivize and even co-finance the wastewater sector and promote small- and medium-scale entrepreneurs (WWAP 2017; Murray *et al.*, 2011). However, benefits arising from PPP projects in the water sector are contested and the need to integrate social and environmental considerations in the PPP is well established (Martin 2009; Stringer *et al.* 2018). Sustainable financing for water pollution may benefit from a mix of economic policy instruments that promote an efficient allocation and use of water and reduce water pollution (UNEP 2016)

Actual private investment in water, wastewater and other infrastructure has failed to meet expectations, and has been almost negligible in lowest income countries (Clarke Annez 2006; Foster & Briceño-Garmendia 2010; Gleick 2014; Hall & Lobina 2006). Public sector investment, financed by both tax revenues and utility surpluses, has been the key to development of water infrastructure both in high income countries, including France, and in developing countries, where the MDG for drinking water was met ahead of target (Foss-Mollan 2001; Pezon 2009; Hall & Lobina 2012). For governments and civil society (groups A and B), public finance is more susceptible to democratic accountability and control. Formal techniques, such as cost-benefit analysis, have been used for many decades to evaluate government decisions on investment in water resources, water supply and sanitation (Haveman 1965; Gunter & Fink 2010).

Investment by small farmers, especially with public sector support, can result in more sustainable and biodiversity sensitive investment in irrigation (Xie *et al.*, 2014; Woodhouse *et al.*, 2017; Fraiture & Giordano 2014) and public sector investment in irrigation can successfully reflect economic and resource factors (Rosegrant & Pasandaran 2016), whereas the use of market mechanisms by raising prices impacts farmers' income without improving efficiency (Varela-Ortega *et al.*, 1998). Meanwhile, Natural Capital Accounting could provide an option for the efficient use of scarce natural resources. The WAVES partnership, for example, has supported Botswana, Madagascar and Rwanda to develop accounting methods which include natural capital (Waves Partnership 2013; Stringer *et al.* 2018).

IPLCs have often expressed that engagement in water management is generally limited to consultative capacity through ineffective representative processes (Behrendt & Thompson 2004; Hunt *et al.*, 2009). The development of partnerships optimizing IPLC participation offers substantial opportunities for greater IPLC engagement in water management (Tinoco *et al.*, 2014; Escott *et al.*, 2015; Jackson & Barber 2015). Capacity building relevant to water resources management (Jackson & Altman 2009; Hoverman & Ayre 2012), financial support to allow for participation (Jackson *et al.*, 2009; Escott *et al.*, 2015) and greater consideration of ILK and IPLC cultural values (Mooney & Tan 2012; Nikolakis *et al.*, 2013; Maclean & The Bana Yarralji Bubu Inc. 2015) have been deemed as key enabling factors for fostering effective IPLC participation in water governance (Escott *et al.*, 2015).

6.3.4.6 Promoting Integrated Water Resource Management

Fostering polycentric governance: Particular institutional challenges of catchment-level governance are the reluctance of existing power structures to devolve authority (Jager *et al.*, 2016; Moss 2012; Ring *et al.* 2018) and to move beyond specific pollutants to more systematic governance. Implementation of the Water Framework Directive (WFD) illustrates how many member states have maintained existing structures and procedures while resisting the transfer of power to new river basin authorities (Jager *et al.*, 2016; Ring *et al.* 2018). Failure to implement plans also often compromises the delivery of WFD objectives (Voulvoulis *et al.*, 2017). Implementing polycentric governance remains a key option. For example, the South African National Water Act (1994) aims to adopt a system of polycentric governance at the level of 19 Catchment Management Authorities. While the approach has seen some of the challenges of devolution discussed above, it has been successful in addressing cross-sectoral integration (Muller 2012; Stringer *et al.* 2018).

***Facilitating integration across sectors*:** IWRM enables decision makers to move beyond single-issue policies. Linking land-use and water planning for example has resulted in large urban populations gaining access to water and sanitation (GEO6 H20 chapter; PanEurope GEO6; North American GEO6; LAC GEO6). Understanding telecouplings between distant natural and human systems are an important option for holistic approaches to managing complex socio-ecological systems (Liu 2013; Liu 2015). Consideration of the Water-Food- Energy nexus contributes to taking telecoupling between distant and local drivers of change into account when implementing IWRM (e.g., Stringer *et al.* 2018). In addition, such integration would benefit from the application of social science research to enable greater inclusion of knowledge from policy and political science and public administration and provide important insights into watershed governance (Sabatier *et al.*, 2005; McDonnell 2008; Cook & Spray 2012; Lubell & Edelenbos 2013).

Harness international normative framework: Adoption of integrated watershed, catchment and river basin management strategies is emphasized as one option to maintain, restore or improve the quality and supply of inland water resources (CBD COP Decision IV/4 (1998)). The UNECE Water Convention on the Protection and Use of Transboundary Watercourses and International Lakes (1992) requires parties to take "all appropriate measures" to conserve and restore ecosystems (Article 2). These include the establishment of water quality objectives and criteria, conservation and restoration of ecosystems, and development of concerted action programmes for the reduction of pollution. The Ramsar Convention on Wetlands (e.g., Resolution VIII.16, 2002) also emphasizes the importance of restoration and the inclusion of multiple actors including private landowners, NGOs, and IPLCs in wetland restoration planning and implementation (WWAP-UN Water 2018). A key option for riparian governments and NGOs is to harness the international normative framework to implement national and watershed scale measures. This includes the development of legal instruments and policies for controlling alien species and wetlands restoration – e.g., the Working for Water (WfW) programme pays actors to remove invasive alien species in South Africa while enhancing the capacity and commitment to solve invasive species issues (https://www.environment.gov.za/projectsprogrammes/wfw). (See section 6.3.2.5 for ecosystem restoration).

6.3.4.7 Encouraging transboundary water management

The IWRM options (section 6.3.4.6) are also applicable to the transboundary context. In addition, further options are set out below.

Implementing international law norms and basin treaties: Existing international obligations provide the normative framework and a level playing field for basin level implementation at national and transboundary levels. For example, the UN Watercourses Convention's process-based norms offer options for interpreting and implementing the convention and implementing an effective system at the national level (Rieu-Clarke & Lopez 2013). In addition, basin level treaties can offer effective mechanisms for managing transboundary basins and preventing the escalation or emergence of transboundary disputes (Brochmann & Hensel 2009; Tir & Stinnett 2012; Dinar *et al.*, 2015). The content and design of such treaties need particular consideration (Dombrowsky 2007). For instance, options for securing compliance include strong mechanisms for dispute resolution (UNEP 2002; Lim 2014) and recognition of non-state parties (Jacobson & Brown-Weiss 1998). On the other hand, sanctions are the least effective in terms of implementation across national borders (Brunée 2007).

Addressing fragmentation: Regime fragmentation is a key obstacle of the law of transboundary watercourses (Zawahri 2011; Rieu-Clarke & Pegram 2013) as there is a common trend to adopt bilateral agreements within multilateral river basins (Song & Whittington 2004). The second assessment of the implementation of the UN Watercourses Convention emphasizes the importance of integrating sectorial policies to avoid perverse outcomes (European Commission for Europe 2011). The UN Watercourses Convention and the UNECE Water Convention are the two main international Conventions governing the management of transboundary water resources. Both are in force, open to all countries and mutually reinforcing (McCaffrey 2014). Rieu-Clarke and Kinna (2014) therefore recommend a 'package approach' and three institutional options for States to address fragmentation while simultaneously implementing both Conventions. The first option suggests that the UNECE Secretariat would be responsible for servicing both Conventions. The second envisages two parallel institutional frameworks where each Convention has its own Secretariat. The final option is to maintain the *status quo* where contracting states would not need to make any amendments to the two existing Conventions.

Strengthening participatory tools: Data sharing provisions within transboundary agreements is an important option for enhancing effective transboundary water resource management. Even where data is shared, concerns often remain over their veracity (Turton *et al.*, 2003; Timmerman & Langaas 2004; Grossmann 2006; Armitage *et al.*, 2015; Gerlak *et al.*, 2011). Conversely, data and information can facilitate transparency and trust which in turn enhances compliance (Young 1994; Burton & Molden 2005; Gerlak *et al.*, 2011). In addition, improved stakeholder engagement and enhanced capacity for integrated problem solving are key components of the success of the transboundary endeavor (Dore *et al.*, 2012; Lim 2014). Where stakeholders perceive particular rules to have emerged from a legitimate process, they are more likely to comply with their commitments (Franck 1998; Jacobson & Brown Weiss 1998; Breitmeir *et al.*, 2006; Brondizio & Le Tourneau 2016; Diaz *et al.*, 2018).

6.3.5 Integrated Approaches for Sustainable Cities

Urbanization is one of the most forceful drivers of ecological change (Seto 2013), with more than two thirds of the world's population expected to live in cities by 2050 (United Nations 2010). The most significant growth in urbanization during the 21st century will occur in the developing world, particularly Africa and India, which combined will add more than 1 billion *new* urban residents by 2040 (UNDESA 2014). In urban areas human populations and human built infrastructure are the most dense (Grimm *et al.*, 2008), and can drive significant impacts on local, regional, and global nature and its sustained contributions to people's quality of life if not managed properly (McPhearson *et al.*, 2018). More than half the global urban population lives in settlements of less than one million, and attention is needed across the urban hierarchy, from global cities to towns and small villages (UN Habitat and United Nations ESCAP 2015).

Globally, urban land cover is projected to increase by 1.2 million square kilometers by 2030. This could result in considerable loss of habitats in key biodiversity hotspots, including the Guinean forests of West Africa, the tropical Andes, the Western Ghats of India, and Sri Lanka (Seto *et al.*, 2012), and of Mediterranean habitat types (Elmqvist 2013). Yet despite major changes to ecological properties, critical NCPs are still present in urban settings (Gomez 2013a, Gomez 2013b). An array of options for the protection, adaptive management and restoration of nature in cities are thus critical to maintain a supply of nature's contributions to urban populations and are essential to engender more sustainable futures for city inhabitants (McDonald 2013; McPhearson *et al.*, 2014).

Planning for the impacts of climate change on urban settlements is also a core challenge for our urban future, as highlighted by the inaugural IPCC Conference on Cities and Climate Change in early 2018. Cities consume 75% of the world's energy use and produce more than 76% of all carbon, and are therefore major contributors to climate change, but are also highly vulnerable to risks, especially in coastal locations (Bai *et al.*, 2016). Reducing the impact of climate change will require a more integrated approach to urban design, planning and construction; urban ecosystems; and transport, energy, water and urban governance (Rosenzweig *et al.*, 2016). It will also require implementation by all levels of government – both national urban policy and state and local strategies and actions (OECD 2010), yet many barriers exist that prevent integrated urban approaches, ranging from financial challenges to lack of information to sectoral fragmentation (Runhaar *et al.*, 2018)

The good news is that urban planning and policy in cities around the world are already developing novel approaches, methods, and tools for developing sustainable cities, including in developing countries (Norman 2016, McEvoy *et al.*, 2013, Measham *et al.*, 2011). This section reviews options in the short and longer-term to enable sustainability transitions in cities, while recognizing that the challenges, and thereby the options, differ in the global South and North (Nagendra *et al.*, 2018). The section focuses on the main groups of options for sustainable cities: urban planning for sustainability; nature-based solutions and green infrastructure; reducing the impact of cities; and enhancing access to urban services for a good quality of life (see for an overview **Table 6.6**).

Table 6 6 **Options for sustainable cities.**

Short-term options (both incremental and transformative)	Long-term options	Key obstacles, potential risks, spill- over, unintended consequences, trade-offs	Major decision maker(s)	Main level(s) of governance	Main targeted indirect driver(s)
Urban planning for sustainability					
Bioregional planning		Traditional urban planning that focuses only on development	National & local government, civil society	National, regional, local	Economic, demographic, Institutions, governance
Nature-friendly urban development		Lack of understanding of habitat needs of animals and plants	National & local government	National, regional; local	Institutions, governance
Increasing green space		Trade-offs between densification and green space, increasing land prices	Local government	Local	-
Protecting land for urban agriculture and food security		Zoning that limits urban food production, increasing land prices	Local government, civil society	Local	Cultural
Nature-based solutions and green infrastructure					
Promoting or requiring green roofs to counterbalance temperature effects		Resistance to requiring GI by law, increases in maintenance costs, lack of incentives	National and local government	National, local	-

Short-term options (both incremental and transformative)	Long-term options	Key obstacles, potential risks, spill- over, unintended consequences, trade-offs	Major decision maker(s)	Main level(s) of governance	Main targeted indirect driver(s)
Planting trees to reduce air pollution, mitigate climate change and storm-water control		Trade-offs between densification and green space, concerns about liability and building damage, costs of maintenance	Local government, civil society	Local	-
Protecting watersheds and wetlands for habitat conservation, clean water supply and storm-water control		Trade-offs with other land uses, pressures for development of coastal areas	Regional and local governments	Regional, local	Health
Protecting, creating or restoring wetlands, tidal marches or mangroves for flood protection		Trade-offs with other land uses, pressures for development of coastal areas	Governments	Regional, local	-
Reducing the impacts of cities					
Encouraging articulated density to enable public and active transportation (e.g walking, bicycles)		Trade-offs between densification and green space; changes in lifestyle needed	Regional and local governments	Regional, local	Economic, demographic, cultural, Institutions, governance
Reduce transport energy use through road-use pricing, promoting public transportation		Changes in lifestyle needed, political will to increase taxes on externalities	Governments	National, regional, local	Cultural
Mitigating building energy use by energy-efficient building codes		Resistance to requiring codes by law, costs of retrofitting	Industry, governments	Local	Technological
Addressing urban consumption by encouraging alternative business models		Change in lifestyle needed, planning for circular economy needed	Governments, industry, civil society	All	Economic, Cultural, institutions, governance
Enhancing access to urban services for good quality of life					
Enhancing access to clean water and sanitation, through SUWM, partnerships, investment, etc.		High costs for water infrastructure, concerns about private sector involvement, sectoral siloing	Governments, industry, civil society, private sector	Local, regional	Economic, governance
Improving management of solid waste through incentives & other programs		Difficult to reach informal settlements	Local government, civil society	Local	Economic
Improving access to transportation by investing in public and active transportation		High cost; major shift of focus needed in transportation planning	Governments	National, regional, local	Economic
Encourage participatory planning approaches		Challenges entrenched interests and authorities	Local governments	Local	Governance

6.3.5.1 Urban planning for sustainability

The SDG, UN Habitat (Quito 2016) and the World Urban Forum (Kuala Lumpur 2018) have all collectively reaffirmed the positive contribution integrated strategic urban planning can make in protecting nature within and around cities (Folke *et al.* 2002; Norman, 2018). Over the past few decades, “ecocities” and “green cities” theories began to emphasize the importance of ecosystems within cities and in linked rural areas (Yang 2013). Sustainable urban design seeks to maximize the quality of the built environment and minimize impacts on the natural environment (McLennan 2004). Innovative urban planning theories have emerged, such as Ecological Design (Rottle & Yocom 2011), New Urbanism, Sustainable Urbanism (Farr 2008), Ecological Urbanism (Mostafavi & Doherty 2010), Agricultural Urbanism (De La Salle and Holland 2010), Landscape Urbanism (Waldheim 2007), Green Urbanism (beatley 2000), Biophilic Urbanism (Beatley 2009), Ecocities (Register 2006), and Ecopolises (Ignatieva *et al.*, 2010). These approaches emphasize ecological restoration and connected multifunctional green infrastructure, prioritize walkable and mixed land uses (Register 2006).

Options for sustainable urban planning include: bioregional planning; nature-friendly urban development; increasing green space in cities; and protecting land for urban agriculture (see Supplementary Materials 6.4.1 for a detailed discussion).

- *Bioregional planning:* Inter- and transdisciplinary, collaborative, and strategic urban planning and design that integrates with surrounding regions can offer numerous benefits to water, renewable energy, and air quality (Breuste *et al.*, 2008; Raudsepp-Hearne *et al.*, 2010; Beatley 2011; Colding 2011; Novotny *et al.*, 2010; McDonald & Marcotullio 2011; Pauleit *et al.*, 2011; Ignatieva *et al.*, 2010; Ahren 2013; Carmen *et al.*, 2013; Alexandra *et al.*, 2017).

- *Nature-friendly urban development:* Ecosystems are often highly fragmented in urban areas, which can alter the genetic diversity and threaten long-term survival of sensitive species. To ensure viable urban populations, urban planners need to understand species' needs for habitat quality and connectivity (Kabisch *et al.*, 2017; Braaker *et al.*, 2014; Colding 2011). Ecologically progressive urban planning and policy are already demonstrating how biodiversity conservation and management to enhance local ecosystem services production can be part of urban transitions and transformations for sustainability (Kabisch *et al.*, 2017).

- *Increasing green space and greenbelts throughout cities*: GIS and other holistic spatial planning tools and technologies can be used to create new green spaces and improve and connect existing ones using (Pickett & Cadenasso 2008; Vergnes 2012).

- *Protecting land for urban agriculture and food security*: Urban and peri-urban agriculture, in the form of private gardens, vegetated rooftops, or vertical gardens can both increase food security and conserve biodiversity. Demonstrating that urban agriculture reduces environmental deterioration, increases food security, produces jobs, and connects communities can support rezoning efforts and integration with climate adaptation and flood mitigation policies (Smit 1996; Resource Centers on Urban Agriculture and Food Security).

6.3.5.2 Nature-based solutions and green infrastructure

Increased use of green infrastructure and other ecosystem-based approaches can help advance sustainable urban development while reinforcing climate mitigation and enhancing the quality and quantity of urban NCP (RUAF 2014; Ecologic Institute 2011; Georgescu *et al.*, 2014). The European Commission defines green infrastructure (GI) as "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed so as to deliver a wide range of ecosystem services" (European Commission 2015). Yet, agreement on what exactly constitutes GI is elusive since the term is often used to refer to interventions across a variety of scales including large national ecological networks, wetland restorations, storm-water projects, public green space, allotments, green corridors, street trees, green roofs and walls, permeable pavements and even private gardens (Cameron *et al.*, 2012; Cohen-Shacham *et al.*, 2016).

Green infrastructure can be a critical source for security and improving human wellbeing in urban areas (Gill *et al.*, 2007; Foster *et al.*, 2011; Depietri *et al.*, 2011). Different types of GI can play a role in providing nature's contributions to urban residents such as storm water management and flood protection, temperature regulation, cleaner air and water, urban food production, recreation, and health benefits, as well as contributing to habitat creation and restoration, connectivity of ecological networks, and increasing urban biodiversity (Andersson *et al.*, 2014; Garmendia *et al.*, 2016). GI is also thought to present the most cost effective and synergistic solution for ensuring local climate change adaptation, and promoting low carbon cities (Fink 2016). For example, incorporating green infrastructure in urban design, especially in warmer climates, can potentially reduce the use of air conditioning, increase significant energy savings, and therefore indirectly reduce GHG emissions (Alexandri & Jones 2008; Georgescu *et al.*, 2014).

Specific options for using GI approaches to address urban problems include the following (see Supplementary Materials 6.4.2 for a detailed discussion).

- *GI to counterbalance temperature effects*: The role of some types of GI (trees, green roofs and green walls, parks, ponds) in regulating temperature, including reducing the effects of urban heat islands, is well established.

- *GI for reducing air pollution*: Vegetation can remove or reduce certain pollutants from the atmosphere, including greenhouse gas emissions through carbon sequestration, and trees act as carbon sinks in urban settings (McPherson 1998; McPherson & Simpson 1998).

- *GI to provide clean water supplies*: Provisioning of water is a critical nature contribution to people (NCP) provided by ecosystems and protecting watersheds and wetlands within cities and in the region is crucial. This will also support other regulating NCP including flood alleviation, nutrient cycling, and habitat conservation.

- *GI for storm-water management*: The benefits and cost-effectiveness of GI for storm water and flood control in urban areas are well established (Kabisch *et al.*, 2016).

- *GI for storm and flood control:* A growing number of cases are demonstrating the effectiveness of ecosystems as nature-based solutions to buffer the impacts of climatological, hydro-meteorological and even some geophysical hazards such as landslides (Renaud *et al.*, 2016; McPhearson *et al.*, 2018). The creation or restoration of wetlands, tidal marshes, or mangroves provide water retention and protect coastal cities from storm surge flooding and shoreline erosion during storms (Haddad *et al.*, 2015; Gittman *et al.*, 2014; Kaplan *et al.*, 2009). Similarly, "sponge cities" in China, defined as urban development that takes into account flood control and water conservation through infrastructure planning and ecosystem-based protection, are using GI to combat persistent and significant urban flooding challenges (Li *et al.*, 2017).

Notwithstanding the substantial evidence for the benefits of GI as nature-based solutions, some concerns remain relating to trade-offs, protection of biodiversity, and governance and equity issues. Further research is needed to better understand the synergies and trade-offs between the different benefits offered by GI (Haase, 2015). Promotion of GI at present seems to be focused on opportunities for economic growth, enhancing durability of infrastructure, and cost reduction (Garmendia *et al.*, 2016). GI initiatives would benefit from more explicitly incorporating nature conservation objectives, as well as assessing and safeguarding the impacts of GI projects on biodiversity (Eggermont *et al.*, 2015; Garmendia *et al.*, 2016). A recent EU publication noted the need for habitat suitability and mapping of nature's contributions as part of GI approaches (EEA 2014). In addition, it is also necessary to evaluate the degree of transferability and uptake of GI research within the developing world context, since most research originates in developed countries (Shackleton 2012). Barriers to GI implementation often include a lack of incentives, little institutional support, and concerns about increased maintenance costs (Zhang *et al.*, 2012).

Mainstreaming of GI, and nature-based solutions in general, may include several options. First, meaningful participation from multiple stakeholders is essential in order to identify commonalities and differences between stakeholder preferences (Hansen & Pauleit 2014), and to encourage co-production of initiatives to ensure ownership and stewardship (Nesshöver *et al.*, 2017). Secondly, long-term guardianship of urban areas may require recognition and institutional support for diverse forms of property rights arrangements such as Urban Green Commons (e.g. collectively managed parks, community gardens, allotments) (Colding & Barthel 2013), as well as the empowerment of grass roots initiatives that match solutions to demand (Brink *et al.*, 2016). Lastly, urban planning decision-making processes could benefit from incorporating the concept of the insurance value of ecosystems. This refers to placing importance on the role of nature in conferring resilience that secures the long-term conditions necessary to sustain a good quality of life for humans (Green *et al.*, 2016). This can be applied in an urban planning context to help target investments for GI and urban nature restoration, and might even require involving insurance industry sectors as key investors in GI and nature restoration efforts (European Commission 2015). However, despite the recognition of nature-based approaches as "low regret" measures for climate change adaptation and disaster risk reduction at both local (Kabisch *et al.*, 2017) and global levels (UNISDR 2005, 2015; IPCC 2012), such approaches still remain the most disregarded component of urban plans and strategies (Renaud *et al.*, 2013; Matthews *et al.*, 2015).

6.3.5.3 Reducing the impacts of cities

With global populations urbanizing, the environmental impacts of cities have become increasingly large, such as increasing demand for materials to create infrastructure, vehicles and buildings (IRP 2018). Within this context it is necessary to look at the 'solution space' for cities, noting that some directions for alleviating urban environmental impact are at a national or societal level, and international city-peer organisations such as ICLEI or the C40 collective are sharing experiences among cities on reducing impacts.

The literature on resource efficiency indicates that key issues of concern for urban areas are limited reserves, recycling, and reducing consumption, and from this a systems perspective and circular economy ideas of industrial ecology have emerged (Miatto *et al.*, 2016; Heinz Schandl *et al.*, 2016; Schandl *et al.*, 2015; UNEP 2016). It is worth noting that although thousands of cities report on their (usually only direct) GHG emissions, monitoring of the whole urban metabolism of cities is more rare, but increasing (Kennedy *et al.*, 2011; Huang *et al.*, 2015). Research agencies and NGO are beginning to gather data at the national and international scale, and research indicates that network system modeling approaches, global life-cycle perspectives, and multi-criteria assessments can be key tools (Beloin-Saint-Pierre *et al.,* 2017). Urban environmental assessments will need to become as much a part of planning as housing, transport and economics if we are to measure progress in the resource efficiency of cities. The urban literature points to changes in urban density and form, efficient transport, and how people build, consume, and live in cities as key components to increasing efficiency and reducing impacts (Reid Ewing & Cervero 2010; Reid Ewing & Rong 2008; Weisz & Steinberger 2010).

Specific options for reducing the impacts of cities include the following (see Supplementary Materials 6.4.3 for a detailed discussion).

- *Encouraging density and in-filling:* Sprawling cities generally require more energy for transport per capita (Newman & Kenworthy 1989), more car travel, less travel by public transit (Kenworthy & Laube 1999) and accommodate larger floor area in buildings, which consume more electricity (Kennedy *et al.*, 2015). To be an effective intervention for socio-economic and environmental benefit, density must be implemented at key transport nodes, surrounding and linking between activity centres (Suzuki *et al.*, 2013).

- *Planning urban form and transport:* Planners and industry need to create neighborhoods of mixed land use and diverse housing options that pre-empt the need for citizens to travel across the city (Cervero & Guerra 2011; Ewing *et al.*, 2008; Grubler *et al.*, 2012; Marshall 2008). Other options to reduce transport energy use include internalization of external costs (e.g. congestion pricing), making public transport more attractive, and not extending the road network (Grubler *et al.*, 2012).

- *Mitigating building energy use and emissions*: Buildings are the single largest energy use sector within cities world-wide (Weisz & Steinberger 2010). Significant operational savings can be achieved from implementing energy efficient building codes (Pauliuk, Sjöstrand, & Müller 2013) and with new urbanization and replacement of existing stock, there is an opportunity to decouple energy needs from urban growth (UN Environment and International Energy Agency 2017).

- *Addressing urban consumption:* Reducing the indirect impact of urban consumers can be achieved by promoting the selling of services instead of consumer goods that provide the service. Implemented through the 'circular economy', this collectively can help separate material needs from consumption (IRP 2018) (see further discussion in section 6.4 on sustainable economies).

- *Transformative urban governance:* Engaging citizens in planning, including participatory budgets, is an important role for (local) governments (Grubler *et al.*, 2012; IRP 2018).

6.3.5.4 Enhancing access to urban services for good quality of life

One of the main targets of SDG 11 (sustainable cities and communities) is to ensure access for all to basic services. This is especially urgent in cities in the global South, where inhabitants of informal settlements, or slums, have access to few or no services (Nagendra *et al.,* 2018). Reducing informal settlements was one of the Millenium Development Goals, and more steps can be taken to address these targets to enhance the quality of life for the quarter of the world's population that live in informal settlements (UN-Habitat 2015, Richards 2006). Options include increasing access to clean water and sanitation; improving management of solid waste; increasing access to transportation and green spaces; and transforming governance approaches (see Supplementary Materials 6.4.4 for a detailed discussion).

- *Improving access to clean water and sanitation:* Increasing access to sanitation and clean water by fostering partnerships between all actors to encourage a bottom-up, participatory approach, including recognition of where the informal sector provision of water is working, could increase effectiveness and socio-economic benefits (Ahlers *et al.*, 2014; Annamalai 2016; Bonnardeaux 2012; McFarlane 2008). Sustainable urban water management (SUWM) is the umbrella term for adaptive, integrated, participatory delivery of water, and in most cases, barriers to SUWM are not technical, but institutional (Brown & Farrelly 2009; Marlow *et al.,* 2013). In some cases, public-private partnerships may work, while in others not (Koppenjan & Enserink 2009; Zhong *et al.*, 2008). As noted in section 6.3.4, investing in natural ecosystems such as wetlands can also help to conserve biodiversity while helping communities manage their own water supplies (Postel 2005).

- *Improving management of solid waste:* A top-down approach to improve solid waste management could be integrated sustainable solid waste management (ISSWM) policy, which provides a legal framework to enforce effectiveness (Shekdar 2009). Less costly approaches could be incentive programs and tiered trash collection (pay-as-you-throw) which could significantly reduce the amount of solid waste produced and increase the amount of materials recycled (Dahlen 2010; Folz & Giles 2002) and composting or waste-to-energy programs in place (Sharholy 2008).

- *Improving access to transportation:* Access to safe, affordable, accessible, and sustainable public transportation systems helps communities to thrive socially and economically (Litman 2013; Kenworthy 2006; Litman 2006; Newman 2006; Banister 2001; Deakin 2001; Newman 1999; Cervero 1996; Crane 1996). Other options include promotion of low-cost alternative transportation, such as bicycles or ride sharing.

- *Improve access to green space:* As noted previously, green spaces in cities can contribute to NCP provisioning and biodiversity protection, among other advantages such as increasing GQL, promoting healthy physical and mental well-being (Nadja Kabisch *et al.*, 2017; van den Bosch & Sang 2017; Dennis 2016; Gomez 2013; Lee & Maheswaran 2011), and decreasing crime (Bogar 2016; Donovan 2012; Troy 2011; Kuo 2001).

- *Improving participatory planning and governance for inclusion*: One of the targets of SDG 11 is to enhance and expand on participatory and integrated planning at all levels of governance (UN-SDG 11), which can help contribute to GQL. Participatory planning offers views that may otherwise have been neglected (Innes & Booher 2010).

6.3.6 Integrated Approaches for Sustainable Energy and Infrastructure

It is well established that the energy supply sector based on fossil-fuel energy systems is the largest contributor to greenhouse gas (GHG) emissions (IPCC 2014; Bruckner *et al.*, 2014; Van der Voet 2012; McDaniel & Borton 2002). Extraction, storage, transformation and use of energy sources (i.e. the energy, mining and infrastructure sectors) have considerable negative impact on biodiversity and ecosystem services via degrading, fragmenting, polluting and over-exploiting species and habitats, introducing invasive alien species, and contributing to climate change (CBD/SBSTTA/21/5, Jones *et al.*, 2015; McDonald *et al.*, 2009; chapter 2.1). The transition from a fossil-fuel energy based system to renewables has been identified as a necessary action for a sustainable future. This is reflected by SDG 7 (affordable and clean energy), aiming to ensure access to affordable, reliable, sustainable and modern energy for all, as well as to increase the share of renewables in the global energy mix (UNDP 2016; CBD 2016; CBD 2017). Nevertheless, to ensure the sustainability of an energy transition, impacts of renewables on other SDG (Nerini *et al.*, 2017) as well as on nature and NCPs – especially trade-offs between renewable energy oriented land uses and nature conservation, also covered by the Aichi Targets – has to be equally taken into account (Santangeli *et al.*, 2016a, b; for relevant SDG and Aichi Targets see chapter 3) (See Supplementary Materials 6.5 for discussion on associated challenges).

As **Figure 6.5** indicates, expansion of energy oriented biomass (biofuel) production has more serious impacts on nature and NCP than solar and wind energy, although regional differences across the globe are significant. Therefore, in this section, biofuels related issues are assessed in more detail while other renewable energy sources (including solar, wind, hydropower and their mixes) are discussed throughout.

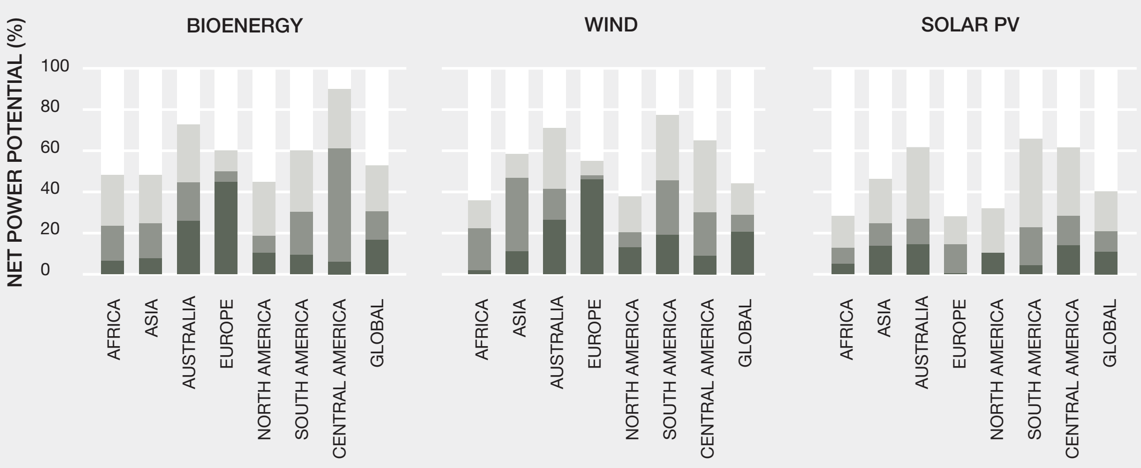

Figure 6 5 **Trade-offs between renewable energy potential and protected areas (Santangeli *et al.*, 2016b).**

Percentage (relative to the total potential of each source) of unrestricted power generation potential available for bioenergy (in the form of *Miscanthus × giganteus*), wind energy and solar photovoltaic summarized by continents and globally. The bars show generation potential within current PAs (Protected Areas; black section of each bar), top ranked areas for 17% PA expansion (dark grey), 17–30% highest ranked areas (light grey) and for the remaining 70% of the landscape (white).

Key governance challenges are the acknowledgement of multiple values in relation to the impacts of current and planned energy use on nature, NCP and GQL, as well as managing trade-offs and telecouplings. Energy use is closely linked to a whole range of political, social and economic interests (Hall *et al.*, 2013; Huber 2013; Mitchell 2011). Institutional interplay across levels – e.g., the course of national borders, the setup of electricity markets, the distribution of property rights, regulations and decision-making processes – defines who owns resources needed for the generation of energy, who gains access to energy, and who bears the burdens (Heindl 2014).

The ways in which energy, mining and infrastructure projects are carried out and implemented trigger conflicts between worldviews and values, raise implementation problems, and often affect IPLC rights to land and water, as illustrated by an increasing number of social-environmental conflicts throughout the world (Arsel & Angel 2012; Rival 2009; Islar 2012; Jordà-Capdevila & Rodríguez-Labajos 2014; Martinez-Allier 2014; Ehara *et al.*, 2016; Spice 2018). At least 40% of all the 2,588 socio-environmental conflicts documented globally happen to involve IPLCs (EJAtlas 2018). Similarly, from the 501 land and environmental defenders that have been assassinated worldwide (2014-2016), almost 40% were IPLCs (Global Witness 2015, 2016, 2017). Disputes over land ownership are an underlying factor in most of these conflicts (Oxfam *et al.*, 2016; Dell'Angelo *et al.*, 2017a, 2017b; RRI 2017). In general, large-scale energy development projects, either renewable or non-renewable, often trigger trade-offs between climate change mitigation, energy provision, social development and nature conservation objectives (e.g., Humpenöder *et al.*, 2018).

Energy production and use are connected by telecouplings to many other ecosystems and resource uses at multiple scales and sectors, raising concerns over biodiversity (e.g., the impact of climate change from energy-related GHG emissions), human health (e.g., the impact of indoor pollution due to inefficient energy technologies), water use and fisheries (e.g., the impact of hydropower), agriculture and forestry (e.g., bio-energy as replacement for fossil fuels), and mining (e.g., rare earth, cobalt, lithium etc. extraction for storage) (Doria *et al.*, 2017).

This section focuses on options for sustainable energy systems exist for various decision makers, including the development of sustainable biofuels strategies, encouraging comprehensive environmental impact assessment, ensuring compensation and innovative financing for environmental and social impacts, ensuring access to energy for all by promoting community-led initiatives, promoting inclusive governance, and promoting sustainable infrastructure **(Table 6.7)**.

Table 6 7 **Options for integrated approaches for sustainable energy and infrastructure.**

Short-term options	Long-term options	Key obstacles, potential risks, spillovers, trade-offs and unintended consequences	Major decision maker(s)	Main level(s) of governance	Main targeted indirect driver(s)
Biofuels strategies					
	Develop sustainable biofuels strategies	• Lack of cross-sectoral policy frameworks • Fragmentation and the lack of coordination between different institutions and sectors • Trade-offs between low GHG energy production and biodiversity	Global institutions, Regional bodies, National and local governments, Private sector, IPLCs	All	Technological, economic
Environmental Impact Assessment					
Improve environmental impact assessment		• Dominance of economic valuation and technical knowledge • Lack of institutional capacity	International bodies, National and local governments, IPLCs	All	Patterns of production and supply

Short-term options	Long-term options	Key obstacles, potential risks, spillovers, trade-offs and unintended consequences	Major decision maker(s)	Main level(s) of governance	Main targeted indirect driver(s)
Compensation and financing					
Strengthen biodiversity compensation policies for development and infrastructure losses		• Compensation does not address root causes of overdevelopment • Difficulties in raising funds in developing countries • Risk for negative impacts on livelihoods by shifting conservation away impacted areas • Ambiguous guidance to developers • Limited capacity for implementation • Inadequate monitoring and enforcement	National, sub-national and local governments, Private sector, IPLCs, Civil society, Landowners and other ecosystem services beneficiaries	National, local	Economic, governance
Promote innovative financing for sustainable infrastructure		• Lack of understanding of novel financial tools (e.g. green bonds and performance bonds) • Concerns about returns of investment • Potential for 'greenwashing'	Global financial institutions National and subnational governments Private corporations	Global, national, subnational	Economic
Community-led initiatives					
Promote community-led initiatives		• Technical and social lock-ins hindering energy independency • Controversial political and economic interests • Energy oligopolies	National governments, Local governments and municipalities, NGOs and cooperatives, Private sector, Citizen and IPLCs	Local, regional, national	Patterns of production and consumption, technological
Inclusive governance					
Promote inclusive governance		• Inappropriate siting of energy infrastructure harming IPLCs • Lack of free, prior and informed consent of IPLCs • Economic interests overruling other aspects	International bodies, National and local governments, Private sector, IPLCs	All	Governance, cultural
Sustainable infrastructure					
	Promote sustainable infrastruc-ture & technology	• Lack of institutional capacity • Lack of economic power • Lack of political will	National and local governments, Universities, Private Sector	All	Technological Patterns of production, supply and consumption

6.3.6.1 Development of sustainable biofuels strategies

Some international organizations (see e.g., IPCC 2014; Searchinger *et al.*, 2017; IRENA 2017), regional organizations (EC 2009) and country governments view biofuel as a clean energy source that support climate mitigation strategies (REN21 2018). Sixty-four countries are in the process of mandating or increasing mandated blending of biodiesel or ethanol in motor fuels, being Brazil, EU, Argentina, Canada and China the largest markets (Edenhofer *et al.*, 2011; IPCC 2014; UN General Assembly 2015; IEA & OECD 2013; Gota *et al.*, 2015; Malins 2015). Favourable taxation and export levies are applied by several countries (e.g., Brazil and Indonesia). Global subsidies for liquid biofuels exceeded US$20 billion in 2014 (Worldwatch Institute 2014). The adoption of biofuel policies has decelerated worldwide but current policies still tend to underestimate risks of biofuels (Goetz *et al.*, 2017; Le Bouthillier *et al.*, 2016; De Man & German 2017; Oliveira *et al.*, 2017; Fargione *et al.*, 2008 – see Supplementary Materials 6.5.1).

At the international and national level, incorporating sustainability criteria in renewable energy laws can recognize the interlinkages between energy use and production, and its impacts on biodiversity (Le Bouthillier *et al.*, 2016; Fritsche & Iriarte 2014; Lin 2012; Frank *et al.*, 2013). For example, the EU Renewable Energy Directive (EU 2009) sets a mandatory 10% minimum target for the share of biofuels in transport petrol and diesel consumption by 2020 to be achieved by all Member States, but to mitigate telecoupling effects it also requires biofuel production to fulfil several sustainability criteria. Options for national governments to mitigate risks of land use change and biodiversity loss related to the expansion of bioenergy production include monitoring and reporting with a focus on potential regulation (e.g., water competition in South Africa), as well as corrective action (e.g., adjustment of the volume of renewable fuels mandated such as in the US and EU). Creating country-wide zoning (e.g., Brazil, Mozambique) can serve as basis of selecting "marginal" or "waste lands" for biofuel production (e.g., India, MNRE 2009), although this is contested in literature (Goetz *et al.*, 2017; Montefrio & Dressler 2016; Baka 2013), especially because such categories, many of which are inherited from colonial occupation, represent rich ecosystems that provide multiple NCP, locally and regionally (Ahmed *et al.*, 2017). Sector-specific zoning (e.g., Brazil's Agroecological Zoning for Sugarcane) and regulation is another option to improve sustainable energy use, which can be interlinked with infrastructure policies. Private sector recently used to implement codes of conduct (e.g., Brazil's Agro-environmental Protocol of the Sugar-based Ethanol Sector) and certification systems (e.g., Indonesian Sustainable Palm Oil), as well as environmental impact assessment and management procedures. However, the current performance of such certifications remains poor, due to the proliferation of low-quality ecolabels and the low market share of certified crops; but also, because ecosystem services and broader cross-sector repercussions of biofuels production and use are not part of such schemes (Gasparatos *et al.*, 2018; German *et al.*, 2017).

Second and third generation biofuels (non-edible plant biomass and unicellular photosynthetic microorganisms, respectively) are promoted as possible alternatives to edible plant based biofuels (Ravindran *et al.*, 2016; Lackner 2015; Mohr & Raman 2013). However, assessments about their effects and associated risks are largely theoretical and premature until these technologies are applied widely (Goetz *et al.*, 2018; Ravindran *et al.*, 2016; Lackner 2015; Mohr & Raman 2013). Second generation biofuels are confronted with sustainability problems similar to those of the first generation (Mohr & Raman 2013). Third generation biofuels (e.g., microalgae) seem to employ significantly less land resources for their production, but their production is very energy intensive and economically unviable today. Technological innovation aims to improve processing technologies as well as microorganisms, pointing to additional risks in form of genetic engineering (Ravindran *et al.*, 2016; Lackner 2015).

For any generation of biofuels to be sustainable, global demand would have to be reduced, and opportunity costs compared to other technologies considered (e.g., photovoltaic, Searchinger *et al.*, 2017). Several governments plan to replace gasoline powered engines by electric ones in the near future to achieve the targets set in the Paris Climate Agreement, which could massively reduce the demand for ethanol and biodiesel. However, advancing e-mobility would amplify other problems, e.g., the production of lithium and other metals and rare earths (Xiong *et al.*, 2018), and expanding it to shipping and air transport (including military) is questionable. Reducing transport volumes, e.g., by shorter supply chains, local production and better public transport, is another option, which would however require far-reaching reforms of the taxation and subsidy system.

6.3.6.2 Encouraging comprehensive environmental impact assessment (EIA)

In the context of energy, the purpose of an environmental impact assessment (EIA) is to assess how the project might cause harm to the environment and to the people and their livelihoods through extraction and infrastructure development. EIA in the mining sector is encouraged worldwide by national laws and international financing organizations (IFC 2012; Equator Principles 2013). While EIA is integrated within the national laws of countries around the world (Morgan 2012; UNEP 2018), case studies demonstrate that social and ecological impacts, IPLC participation, mitigation measures as well as post-monitoring of renewable energy projects may not be adequately addressed in the EIA (Fearnside 2014; Larsen *et al.*, 2018; Schumacher 2017) and weak implementation of EIAs remains a challenge (European Commission 2013). Numerous well established impact assessment methods can be considered helpful for incorporating diverse value systems in the EIA process concerning energy. For example, biodiversity-inclusive EIA offers opportunities for effective participatory mechanisms engaging those who depend the most on nature and its contributions, such as Indigenous Peoples and Local Communities (Akwé: Kon Guidelines 2004; IFC 2012, Standard 7); however, there are associated challenges particularly in developing countries (Craik 2017; Quintero 2012). EIA may also serve as background for "no net loss" and "net gains" biodiversity policies (IFC 2012, Standard 6) using compensatory mechanisms (e.g., offsets), in response to impacts identified in the EIA.

Different options exist to improve EIA practice for energy, mining and infrastructure. Applying the precautionary principle to EIA requires decision makers to identify areas of uncertainty and to consider the implications of knowledge gaps (CBD EIA Guidelines, para. 42). Another option is to incorporate adaptive management into EIA instruments via requirement for ex-post monitoring and follow-up measures (CBD EIA Guidelines, para. 44). Integrating ecosystem services into EIA helps managing trade-offs if implemented in a context-specific manner, by providing a basis to prioritize certain functions and benefits and to identify a wider range of stakeholders affected by potential changes to ecosystem services (OECD 2008; Landsberg 2011; Baker *et al.*, 2013). Such approaches are emerging in EIA practice (European Commission 2013; IFC 2012, Standard 6), but different environmental assessment contexts, resource availability, local capacity and accessible information are likely to drive such integration of ecosystem services (Baker *et al.*, 2013).

Strategic environmental assessment (SEA) has been introduced to expand the scope of impacts by looking at the cumulative effects from programmatic or other spatially related actions (Abaza *et al.*, 2004; UNEP 2018). Challenges aside, widening the scope is possible by incorporating ecosystem services (Slootweg *et al.*, 2010; Geneletti 2013; Landsberg *et al.*, 2013; European Commission 2013; Baker *et al.*, 2013) or integrating Health Impact Assessment with SEA. At present, there is very limited consideration of health in SEA (e.g., in Scotland, Douglas *et al.*, 2011), although good examples exist, e.g., the assessment of health impacts of wind power (Knopper & Ollson 2011; Van den Berg 2003; Pedersen *et al.*, 2004), and the use of the Integrated Environmental Health Impact Assessment approach (Briggs 2008; http://www.integrated-assessment.eu/). See Supplementary Materials 6.5.2 for a detailed discussion on IEA.

6.3.6.3 Ensuring compensation and innovative financing for environmental and social impacts

Compensation approaches have been developed as an instrument to deal with environmental and social effects that cannot be fully avoided or mitigated in energy, mining and infrastructure projects (Koh *et al.*, 2017). Since the 1970's, several countries developed laws and regulations to apply compensatory measures as a requirement for environmental licensing (Rundcrantz & Skärbäck 2003; ten Kate *et al.*, 2004; Rundcrantz 2006). Many compensation approaches are driven by requirements for 'no net loss' of biodiversity – applied now in more than 80 countries – but goals are often challenged by unclear definitions of the baseline reference for 'no net loss' (Maron *et al.*, 2018). Compensation can take form of measures to reduce environmental impacts, to improve social conditions, or monetary payments to offset ecological losses (Villarroya & Puig 2010; Gastineau & Taugourdeau 2014). Recent trends include projects for compensatory mitigation, biodiversity offsets, mitigation banking, habitat banking, species banking, and wetlands mitigation (OECD 2016) (see Supplementary Materials 6.5.3 for a detailed discussion).

There are potential positive effects of compensation schemes, e.g., making new financial resources available for conservation (estimated at several billions per year), reducing the costs of environmental compliance, and supporting the social and economic development of local populations (ten Kate *et al.*, 2004). International experience suggests that no net loss policies combined with biodiversity offsetting and banking can be effective at involving the private sector in conservation, especially relative to widespread uncompensated losses of biodiversity from development projects (ten Kate *et al.*, 2014; OECD 2016; Vaissière *et al.*, 2016). However, there is little comparable data about the amount of compensatory measures and resources allocated for this approach (Villarroya & Puig 2010; Xie *et al.*, 2013). They are intended to be a 'last resort' option, but critiques note that offsets do not address the root causes of overdevelopment of energy, mining and infrastructure projects leading to nature deterioration, and scarcity can create value in markets and banks (Spash 2015). Only a handful of studies have investigated the local impacts of offset projects on IPLCs, which remains a research gap (Bidauda *et al.*, 2017), given that developers who buy offsets tend to be more powerful actors than impacted IPLCs (Apostolopoulou & Adams 2017) and some localized and site-specific biodiversity losses can be irreplaceable (ICMM & IUCN 2012) There is also little literature on the effective use of resources, which makes the results of improving social and economic conditions within project areas inconclusive.

Risks and challenges (see Supplementary Materials 6.5.3) must be addressed for offsetting to deliver on its promise, including the lack of clear policy requirements that offer unambiguous guidance to developers and offset providers (e.g., Quétier *et al.*, 2014), inadequate monitoring and enforcement and lack of political will to require and enforce best practice in offsetting (IUCN 2014; ten Kate & Crowe 2014). More participatory processes of offset definitions and politics have been proposed to address these challenges (Mann 2015).

Standards and obligations for environmental performance or liability in infrastructure and development can mobilize significant amounts of private capital. Innovative mechanisms like performance bonds (whereby a sum of money commensurate with the estimated cost of site rehabilitation is held by a banking or insurance institution to be relinquished upon satisfactory end of the project) are recommended to encourage biodiversity protection during resource extraction, and to ensure sufficient financial sources to restoration after resource extraction activities end (ICMM 2003, 2008). Another new mode of private financing are green bonds, a US$694bn market in 2016, with notably increased use in Asia (Climate Bond Initiative 2017; Clapp 2018). Green bonds raise capital to finance climate-friendly projects in key sectors like transport, energy, building and industry, and water (Croce *et al.*, 2011). Institutional investors are expected to be the dominant buyer of green bonds, and they are touted to provide returns comparable to conventional non-green bonds.

6.3.6.4 Ensuring access to energy for all by promoting community-led initiatives

Energy poverty exists both in developing and developed countries and is embedded in the wider socio-cultural, economic and political context, therefore reflects significant inequalities within and across nations (Brunner *et al.*, 2018; Monyei *et al.*, 2018; Sadath *et al.*, 2017). Citizen's inclusion to renewable energy production and distribution provides more affordable and just energy access, contributes to behavioural change towards more sustainable energy consumption and helps to reduce the adverse impacts of energy use on nature and NCP (Schreuer & Weismeier-Sammer 2010; Rijpens *et al.*, 2013; Kunze & Becker 2015; Islar & Busch 2016). Different types of community-led energy initiatives have emerged all over the world, providing access to clean, reliable and affordable energy. Energy autonomy, realized through decentralized renewable energy production and consumption in local communities and often driven by social and technological innovation to match demand and supply, has been targeted by sustainable and local low-carbon communities in Europe and beyond (Rae & Bradley 2012; Yalçin-Riollet *et al.*, 2014; Hobson *et al.*, 2014; Lee *et al.*, 2014; Hoicka & MacArthur 2018).

Low-carbon communities can take various organizational forms and renewable energy cooperatives (REC) represent a major type which builds on the democratic governance of renewables and provides economic payback to members who join RECs and invest in renewables (Herbes *et al.*, 2017; Hentschel *et al.*, 2018; Heras-Saizarbitoria *et al.*, 2018). Major technological solutions to provide accessible energy to communities in isolated regions include, among others, small-scale photovoltaics (Menconi *et al.*, 2016; Monyei *et al.*, 2018), run-off river hydropower (Egre & Milewski 2002; Wazed & Ahmed 2008), and mixes of different renewable energy sources (Kaldellis *et al.*, 2012). Off-grid, micro-grid and hybrid solutions, applied together with smart technologies, are efficient ways of producing, storing and sharing renewable energy within communities (Menconi *et al.*, 2016). Financing such developments and system transitions may build on public financing and incentives to increase citizen investment (e.g., feed-in tariffs) (Curtin *et al.*, 2017), market based investments (Linnenluecke *et al.*, 2018), and alternative financial models like co-operatives or crowd-funding (Gezahegn *et al.*, 2018; Hall *et al.*, 2018; Vasileiadou *et al.*, 2016). Realizing the urgency of providing modern energy technology and services has also prompted development institutions, such as World Bank and UNDP, to support renewable energy facilities led by communities (UNDP 2012).

Although community-based renewables tend to be less detrimental than large-scale energy development projects as induced land use change is of lower scale and intensity, they might have adverse effects on nature and society (see e.g., Castán Broto *et al.*, 2018; Islar 2012; Aksungur *et al.*, 2011), which has to be mitigated. Overcoming the financial, infrastructural, institutional, socio-cultural barriers of community based renewables is possible if supporting policy is combined with transformation management (Goddard & Farelly 2018), and if governance engages actors from different decision-making levels (Markantoni 2016; Goldthau 2014) and vulnerable groups like women and IPLCs (UNDP 2012) (See Supplementary Materials 6.5.4).

6.3.6.5 Promoting inclusive governance in planning and implementation of energy and infrastructure projects

Excluding local inhabitants from planning energy, mining and infrastructure development projects often leads to socio-environmental conflicts (Finer *et al.*, 2008, 2015; Filho 2009; Kumpula *et al.*, 2011; RAISG 2016; Wilson & Stammler 2016) and legal disputes, coming with severe financial and reputational risks for both states and corporations (Nielsen 2013; Greenspan *et al.*, 2014; Wilson & Stammler 2016). Large-scale infrastructures are often planned and implemented without the Free, Prior and Informed Consent (FPIC) of IPLCs (Hope 2016; Dunlap 2017; MacInnes *et al.*, 2017; Fernández-Llamazares *et al.*, 2018), generally resulting in habitat and biodiversity loss and threatening local livelihoods and good quality of life (Muradian *et al.*, 2003; Escobar 2006; Finley-Brook 2007; Araujo *et al.*, 2009; Finer & Jenkins 2012; Athayde 2014; Laurance & Burgués-Arrea 2017). For example, the rights of Indigenous Peoples in voluntary isolation and initial contact are under assault from infrastructure expansion (Finer *et al.*, 2008; Martin 2008; IACHR 2013; Pringle 2014; Kesler & Walker 2015).

Increased public scrutiny of the social-environmental impacts of extractive activities has led industry to adopt a diverse set of voluntary CSR instruments, including the Extractive Industries Transparency Initiative, the UN Guiding Principles on Business and Human Rights, the Free Prior and Informed Consent, or the Social License to Operate (SLO) (Prno & Slocombe 2012; Business Council of British Colombia 2015; Moffat *et al.*, 2016; Bice 2014). SLO refers to the outcome of engagement processes between industry and communities to establish acceptance of extractive activities (Nielsen 2013; Boutilier & Tgompson 2011), and become central in defining what levels and kinds of social and environmental harm are acceptable, what actions for compensation or restoration are appropriate, and how responsibilities for these actions are distributed (Meesters & Behagel 2017; Idemudia 2007). The concept, however, does not indicate when a SLO is in place, nor does it necessarily imply consent, legitimacy or responsibility of mining activities (Owen & Kemp 2013; Boutilier 2014).

Environmental justice movements, including different forms of IPLC activism, are gaining prominence in response to the expansion of infrastructure development and extraction activities onto IPLC territories (Martínez-Alier *et al.*, 2010, 2014, 2016; Petherick 2011; Athayde 2014; Spice 2018). Mainly through global citizen action, social mobilization and capitalizing on modern technologies, the local social-ecological struggles of IPLCs become matters of global concern (Earle & Pratt 2009; Lorenzo 2011; Temper & Martínez-Alier 2013; Pearce *et al.*, 2015; Januchowski-Hartely *et al.*, 2016). International human rights law protects the right of IPLCs to give or withhold their Free Prior and Informed Consent in relation to resource extraction, infrastructure or energy development projects in their territories (Cariño 2005; Edwards *et al.*, 2011; Ward 2011; MacInnes *et al.*, 2017). Such principle is best understood as an expression of the right to self-determination of IPLCs (Charters & Stavenhagen 2009; Hanna & Vanclay 2013; Doyle 2015) and is enshrined in the UN Declaration on the Rights of Indigenous Peoples, ILO Convention 169, and the Nagoya Protocol on Access and Benefit Sharing, as well as in several national laws (Ward 2011; MacInnes *et al.*, 2017). Although the implementation of FPIC faces several challenges on the ground (Anaya 2005; Perreault 2015; Pham *et al.*, 2015; Dehm 2016), its legal significance is gaining global recognition and lays a solid foundation for simultaneously supporting nature conservation and human well-being (Page 2004; Magraw & Baker 2006; FPP *et al.*, 2016). Increasing engagement of IPLCs in project planning, consultation or social impact assessment is likely to be best served by the adoption of standards and policies such as the Equator Principles, the Global Reporting Initiative, or the UNEP's Policy on Environmental Defenders (Lane *et al.*, 2003; FPP 2007; Yakovleva *et al.*, 2011; UNEP 2018) and binding instruments such as the Escazú Agreement on environmental rights in Latin America and the Caribbean (ECLAC 2018).

A convergence of demand-driven leverage is likely to improve the regulatory stringency and enforcement in countries supplying key mineral resources. For example, in the conflict between IPLCs in Orissa State, India, and the bauxite mining operations of Vedanta Resources (Razzaque 2013), environmental activism, human rights protests and court cases remained ineffective for years, until important shareholders (e.g., the Church of England and the Norwegian government) decided to disinvest in the company, and the government withdrawn the clearances of the mining project (Goodman *et al.*, 2014; Iyer 2015). This case also highlights the possible role of shareholder activism in promoting inclusive governance for energy, mining and infrastructure development (Cundill *et al.*, 2017; Goranova & Ryan 2014). See Supplementary Materials 6.5.5.

6.3.6.6 Promoting sustainable infrastructure

Due to an unprecedented explosion of infrastructure development, extensive areas of the planet are being opened to new environmental pressures (van Dijck 2008; Balmford *et al.*, 2016; Johansson *et al.*, 2016; Gallice *et al.*, 2017; Kleinscroth & Healey 2017) as part of massive infrastructure-expansion schemes—such as China's One Belt One Road initiative (Laurance & Burgues 2017; Lechner *et al.*, 2018) and the IIRSA program in South America (Laurance *et al.*, 2001; Killeen 2007). These new "development corridors", including roads, highways, hydroelectric dams and oil and gas pipelines come with high environmental and social costs, including deforestation (Barber *et al.*, 2014; Fernández-Llamazares *et al.*, 2018), biodiversity loss (Laurance *et al.*, 2001, 2006, 2008; Pfaff *et al.*, 2009; Benítez-López *et al.*, 2010; Sloan *et al.*, 2017), land grabbing (Toledo *et al.*, 2015; Alamgir *et al.,* 2017), social disruption (Mäki *et al.*, 2011; Baraloto *et al.*, 2015) and violation of IPLC customary rights (Fernández-Llamazares & Rocha 2015; Martínez-Alier *et al.*, 2016; Delgado 2017).

The total length of paved roads is projected to increase globally by 25 million kilometres in 2050 (Dulac 2013), with nine-tenths of all road construction occurring in developing countries (Laurance *et al.*, 2014). Given that new roads generate large ecological footprint (e.g., Laurance *et al.*, 2002, 2009), a viable and cost-effective way to avoid habitat loss in areas of high conservation value, also including protected areas, is to keep them road-free by "avoiding the first cut" (Caro *et al.*, 2014; Laurance *et al.*, 2014, 2015; Alamgir *et al.*, 2017; Sloan *et al.*, 2017; Fernández-Llamazares *et al.*, 2018). Another vital tactic is to use large-scale, proactive land-use planning. Approaches such as the "Global Roadmap" scheme (Laurance & Balmford 2013; Laurance *et al.*, 2014) or SEA (Fischer 2007) have been successfully used to evaluate the relative costs and benefits of infrastructure projects, and to spatially prioritize land uses to optimize human benefits while limiting new infrastructure in areas of intact or critical habitats (e.g., Laurence *et al.*, 2018; Laurance *et al.*, 2015; Balmford *et al.*, 2016; Sloan *et al.*, 2018).With many roads becoming rapidly dysfunctional, investing in maintenance represents a more sustainable option than road expansion (Wilkie *et al.*, 2000; Burningham & Stankevich 2005; Luburic *et al.*, 2012; Alamgir *et al.*, 2017).

Infrastructure development related to renewable energy sources can adversely affect nature and humans, decreasing the net benefits and sustainability of renewables (Drewitt *et al.*, 2006; Cohen *et al.*, 2014; Lang *et al.*, 2014; Drecshler *et al.*, 2017). Life cycle assessment can help decision makers choose the best renewable energy source for specific purpose. Along with

EIA or SEA, a landscape approach using geographical information systems can be applied to compare the impacts of different energy scenarios on nature and NCP, by integrating various types of data (Benedek *et al.*, 2018; European Commission 2014; Jones *et al.*, 2015). Resource extraction (e.g., rare earth, cobalt, lithium) for assembling electrical components of renewable energy production, especially batteries and photovoltaics, will further increase and affect the environment (Fthenakis 2009; Larcher & Tarascon 2015). Sustainable mineral sourcing could be improved via global governance which sets and monitors international targets (Ali *et al.*, 2017). Geological exploration plans considering the overlap between protected areas and the prevalence of mineral resources (e.g., the MiBiD index) could further decrease the impact of mining on nature (Kobayashi *et al.*, 2014). Similarly, the negative impacts of energy-related infrastructure can be mitigated through the use of land-use zoning to identify sensitive areas (e.g., Laurance *et al.*, 2015; Balmford *et al.*, 2016; Sloan *et al.*, 2018) or through sensitive operating practices – e.g., turning off wind turbines when large numbers of soaring migratory birds are passing (Hüppop *et al.*, 2006; Allinson 2017).

Dams – producing hydropower, improving navigation or providing secure water supply (Nilsson *et al.*, 2005) – also have largescale landscape impacts (e.g., Belo Monte Dam in Brazil, Lees *et al.*, 2016). More than 50,000 dams above 15 m height exist worldwide (Lejon *et al.*, 2009), and several examples point the significant negative impacts they have on nature and society (Tullos 2009; Finer & Jenkins 2012; Fearnside 2016; Dudgeon 2010; chapter 4; Doria *et al.*, 2017; Beck *et al.*, 2012), which are often not well mitigated (Zarfl *et al.*, 2015; Poff & Schmidt 2016; Winemiller *et al.*, 2016; Latrubesse *et al.*, 2017).

Despite their negative environmental and social impacts, dams may generate new benefits (Menzie *et al.*, 2012), such as create habitat for protected species, or function as a refuge under climate change, making it difficult to consider biodiversity trade-offs associated with decisions about dam removal (Lejon *et al.*, 2009; Beatty *et al.*, 2017). While many studies show positive effects of dam removal on biodiversity (e.g., O'Connor *et al.*, 2015), others highlight unintended risks and consequences, such as dispersal of invasive fish (Lejon *et al.*, 2009), colonization of non-native plants (Tullos *et al.*, 2016) or spread of accumulated contaminants (O'Connor *et al.*, 2015). Case studies also show that deliberations about dam removal tend to create situations where locals become divided between environmental, economic, and cultural losses and gains (Reily & Adamowski 2017). In sum, the complex consequences of dam-removal are unresolved, and studies are typically not framed to inform management concerns that are context-specific (Tullos *et al.*, 2016). See Supplementary Materials 6.5.6.

6.4 TRANSFORMATIONS TOWARDS SUSTAINABLE ECONOMIES

The publication of the *IPCC special report on global warming of 1.5°C* made clear that under current development trajectories global warming will exceed 1.5°C during the coming two decades (IPCC 2018). Similarly, it has become evident (this report; UN 2018) that achieving the internationally-agreed 2030 Sustainable Development Goals and the 2050 Vision for Biodiversity will require transformative change towards sustainable economies. This is the context within which progress towards sustainable landscapes, marine and ocean systems, freshwater management, urban systems, and energy and infrastructure are subsumed, and for which they represent vital parts of the solution.

A plethora of definitions for a sustainable economy have been suggested (e.g., King & Slesser 1994; Bartelmus 1999; Pearce & Barbier 2000; Urhammer & Røpke 2013; Pullinger 2014; Martin 2016). In the IPBES context it can be defined as an economy that does not produce the indirect and direct drivers impinging on nature, nature's contributions to people, and a good quality of life, and account for the important role that telecoupling, trade, supply chains, and producer-consumer interactions now play in our global system. This requires that economic, social and technological indirect drivers and the patterns of production, supply, and consumption that make up the economy respect ecological limitations and ecosystem integrity (Raworth 2015; Bengtsson *et al.*, 2018).

A sustainable economy must also provide more equitable access to the fruits of development and quality of life (O'Neill *et al.*, 2018). Some impacts on nature can be caused by poorer households forced to exploit natural resources due to a lack of other economic options, although the poor are often well aware of their dependence on nature and protect biodiversity (Martinez-Alier 2002). Other data suggests that it is inequality in particular that may lead to negative impacts on the environment as wealth concentrates among people who are not willing to pay for the provisioning of public goods (Boyce 1994; Kashwan 2017). Policies aimed at reducing poverty and inequality thus have the potential to be linked up with priorities for NCP conservation (Johnson 1973). Rethinking what makes an economy sustainable thus will need to focus not only on incorporating pluralistic values of nature, as this report has noted, but also rethinking what it means to have a good quality of life, and how it links to nature and its contributions (Naeem *et al.*, 2016). The concept of an "adequate standard of living" as a human right derives from the Universal Declaration of Human Rights (UN 1948). Policies to achieve a "social protection floor" to protect this right include measures and institutional reforms to achieve both basic income security and universal access to essential, affordable social services (UN 2018). These aims could be combined with more nature-specific measures and attention in the 21st century, such as including ideas about access to NCP as part of social protection measures.

Further, a sustainable economy must be one in which climate change causes and impacts are addressed, to ensure that carbon emissions do not remain an environmental externality, that globalization does not exacerbate the impacts of climate change, and that communities have sufficient financial means to reduce vulnerability and adapt to forecasted changes (O'Brien

Table 6 8 **Options for transformation to sustainable economies.**

Short-term options	Long-term options	Key obstacles, potential risks, spill- over, unintended consequences, trade-offs	Major decision maker(s)	Main level(s) of governance	Main targeted indirect driver(s)
Reforming Subsidies					
Assess impacts of all subsidies policies (e.g. energy, fisheries, agriculture, water); removal of cost ineffective subsidies	Long-term removal of all environmentally-unsound subsidies	Vested interests opposed; political challenges: beneficiaries of subsidy policies protest their removal; welfare impacts of subsidy removal for some communities	National; sub-national; and local governments; research & education organizations	National and sub-national	Economic, institutions
Address over and under consumption					
'Nudges' to consumers; product labelling; local reuse or fix-up initiatives; corporate or NGO led initiatives to discourage overbuying; taxes on consumption; consumer reduced-consumption movements	Expansion of sharing economy; transition towns; sufficiency orientation of consumers; design for sustainability for products and services	Beliefs in rationality of markets; dogma of consumer sovereignty; lack of policies that address leakage & telecoupling; political risks for tax increases; potentials for consumer backlashes	Citizens; private sector; national governments; NGOs; scientific groups	National and local	Economic, cultural
Reducing unsustainable production					
Taxes on resource consumption and degradation; circular economy models; use of LCA as policy tool; corporate social responsibility (CSR)	Circular economy; change production systems based on LCA; capping of resource consumption	Lack of data and research on efficacy; market forces promoting growing production; insufficient consumer interest	National, sub-national and local governments; private sector; NGOs	National and local	Economic, cultural
Reforming trade regimes and financial systems					
Changes in trading rules; stricter regulation of commodity futures markets	Reforming trade system & WTO; future regulation on environmental derivatives	Vested interests opposed; complexity and opaqueness of information	National governments; intergovernmental institutions	All	Economic, institutions
Reforming models of economic growth					
Use of alternative measures of economic welfare and Natural Capital Accounting	Move toward steady state economics paradigm and degrowth agenda	Mostly academic exercises so far; lack of clarity on how to achieve steady-state or degrowth; political risks of not supporting economic growth at all costs; initial welfare impact of recession or degrowth; need to reallocate large sector of economy	Global institutions; national governments; private sector	All	Economic, governance, institutions

& Leichenko 2000; Stern 2006; Betzold & Weiler 2017). Failure to act now on reducing emissions is likely to impose severe economic risks to economies around the globe (Stern 2006; Hsiang *et al.*, 2017), yet recent modelling notes the particular challenges of holding warming to 1.5 degrees given strong economic inequality, high dependence on fossil fuels for global trade and transport, and inadequate climate policies (Rogelj *et al.*, 2018). While many policies have as their stated goal a nexus of nature protection, climate mitigation or adaptation, and poverty reduction, successes in this area are still difficult to find (Boyd *et al.,* 2007, Reynolds 2012, Caplow *et al.,* 2011, Lowlor *et al.,* 2013).

This transformation of the global financial and economic system towards sustainability is both necessary and possible, as the current system increasingly reflects dominant power and geopolitical interests rather than a commitment to sustainability and equity. Aichi Biodiversity Target 4 calls for governments, business and stakeholders at all levels to take steps towards "sustainable production and consumption", as does SDG 12 (responsible consumption and production) (Bengtsson *et al.*, 2018) (section 6.4.2 and 6.4.3). International systems of trade and national systems of positive and negative subsidies are also tools for achieving more sustainable ends (section 6.4.1 and 6.4.4). Finally, there are alternative models of the economy (including green growth and degrowth) to achieve a good quality of life without contributing to degradation of nature and nature's contributions to people (see section 6.4.5). There are a number of possible options for decision makers to begin to transform our economic system into a more sustainable one, ranging from immediate short-term options and longer-term options that may take decades or more to implement. Given the size and scope of the global economy, encompassing all levels from local economic output of firms to global trade between nations, different options can be applied at different scales, from individual consumers up to international institutions. This section provides a review of these options **(Table 6.8)**.

6.4.1 Reforming environmentally harmful subsidy and tax policies

Aichi Target 3 calls for the elimination, phasing-out or reform of incentives, including subsidies, that are harmful to biodiversity. It is estimated that financial support to agriculture that is potentially environmentally harmful amounted to USD 100 billion in OECD countries in 2015, and that fossil fuel subsidies account for USD 345 billion globally (OECD 2017a). The amount of finance mobilized to promote biodiversity is therefore conservatively estimated to be outweighed by potentially environmentally harmful subsidies by a factor of 10. Other potentially environmentally harmful subsidies that may also adversely affect biodiversity and ecosystems include those that encourage overcapacity in the fishing and forestry sector, subsidies that encourage urban sprawl, and the over-consumption of water.

Given the magnitude of these harmful subsidies, governments should consider the fiscal and environmental implications of their policies and work to identify and assess both their direct and indirect impacts on terrestrial and marine ecosystems. Many of these support policies were put in place for other reasons, such as to maintain the economic viability of rural areas, but such objectives can be achieved with policies that promote public goods, rather than the over-exploitation of natural resources. Reducing harmful subsidies and increasing positive environmental subsidies allows countries to compensate for the cost of adopting environmentally friendly production and consumption behaviour and by so doing, encourage such behaviour. Examples of positive subsidies with outcomes on biodiversity include grants to farmers who construct contour bunds on steep slopes, which is a policy within both the US Conservation Reserve program and the EU CAP (see **Box 6.5**).

Agricultural subsidy policy reform has already taken place with success in some countries; agricultural subsidies were reformed in Switzerland and New Zealand, and pesticide

Box 6 5 **Positive Subsidies.**

The EU Common Agricultural Policy (CAP) has long tried to use generally voluntary schemes aiming at providing incentives to farmers to conserve and better provision ecosystem services on their individual farmlands and prevent agricultural land degradation (e.g. overuse of pesticides or tillage). Under CAP, farmers are required to make a five-year obligation to use environmentally friendly farming practices (for example, conservation set-asides, organic agriculture, low-intensity systems, integrated farm management; preservation of landscape of high-value habitats and biodiversity, etc. (CDB 2015), and they receive payments to cover the cost of these enhancements or income lost from doing so. However, the agri-environmental payments of the CAP in particular are reported to have only a moderate positive impact on biodiversity (e.g., Capitanio *et al.*, 2016; Overmars *et al.*, 2013; Whittingham 2011; Kleijn *et al.*, 2006; Primdahl *et al.*, 2003) (see Ring *et al.,* 2018, section 6.5.2).

subsidies were removed in Indonesia (OECD 2017c). Subsidy reform can be combined with other measures, for example removing harmful subsidies from livestock production, imposing taxes, and internalizing social and environmental externalities in food production costs (Stoll-Kleemann & Schmidt 2017). However, the full impact of removal of subsidies on biodiversity and nature is not well understood, given the long time-lags necessary to judge such impacts.

In another example, removal of inappropriate subsidies to fossil fuel energy will help reduce carbon emissions. Estimates of the global costs of subsidizing fuels from 2012 to 2015 range between US$300-680 billion per year depending on accounting methods (Franks *et al.*, 2018). G7 countries alone provided at least $100 billion annually in subsidies for the production and consumption of oil, gas and coal, despite pledges from these countries to reduce them (Whitley *et al.*, 2018). Reducing energy subsidies and spending these funds instead on SDG would allow many countries to go a long way towards meeting their domestic financing needs. For example, Vietnam has annual per-capita fuel subsidies of US$35, which would cover an estimated one quarter of funding needed to meet their SDG commitments (Franks *et al.*, 2018) (see **Figure 6.6**). India, Indonesia, and Mexico recently reduced their subsidies for transport fuels, and major reforms of fuel or electricity prices are taking place in Argentina, Egypt, Iran, the Gulf Co-operation States, and Morocco (OECD 2017a; Rosas-Flores *et al.*, 2017; Wesseh *et al.*, 2016; Bhattacharyya *et al.*, 2017). Iran was able to end ecologically undesirable fuel subsidies by instituting a universal dividend while phasing out subsidies (Tabatabai 2012), and subsidy removal can result in opportunities for conservation and potential energy savings, as shown in in Malaysia (Yusoff & Bekhet *et al.*, 2016). China has also recently removed some energy subsidies (Jiang *et al.*, 2015; Lin *et al.*, 2014; Lin & Li. 2012) reporting both economic and environmental gains (Hong *et al.*, 2013). The starting point for energy subsidy reform from these cases points to the need to clearly define the policy objectives, understand the distribution of the costs and benefits of subsidies, assess economic as well as social and environmental impacts, actively promote the dissemination of information to stakeholders, and engage with all relevant parties (Barg *et al.*, 2006).

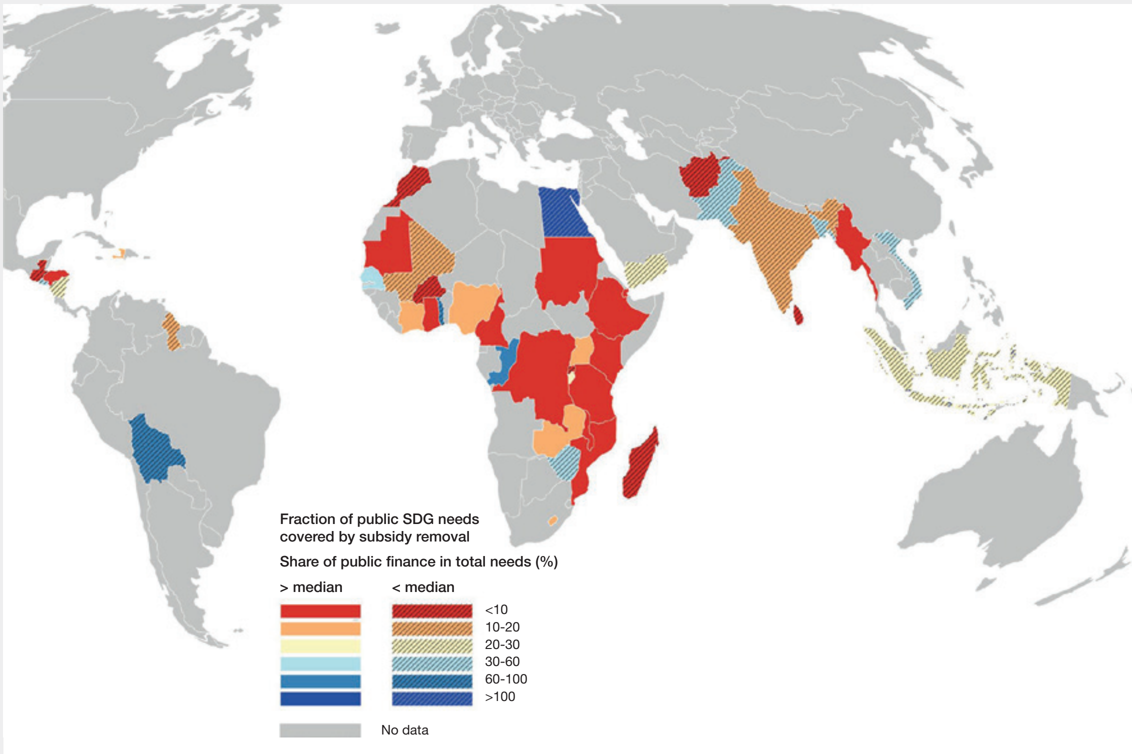

Figure 6 6 **Fraction of the national public investment need for the SDG agenda that could be financed by freeing up funds that are used at present for subsidizing fossil fuels.**

Source: Franks *et al.* (2018).

In the fisheries sector, subsidies have been estimated to be at least 13 billion per year (OECD, 2017b; Sala *et al.,* 2018). Many governments subsidize fishing by national fleets, often exceeding the net economic benefit. Fisheries subsidy reform took place in Iceland, New Zealand and Norway in the 1990s in attempts to reduce pressure on fishing stocks but remains a problem in many other countries and in particular in High Seas fishing. A recent review of High Seas fishing found that without subsidies and low wages (often slave level labor), "more than half of the currently fished high-seas fishing grounds would be unprofitable at present exploitation rates" (Sala *et al.*, 2018) (also see section 6.3.3.3.2).

International action can help countries become motivated to tackle subsidy reform, such as through "informal international law" (Pawley *et al.*, 2012). They include declarations by the leaders of the Group of Twenty (G20), the Group of Seven (G7), and the Asia-Pacific Economic Cooperation (APEC) countries. SDG target 14.6 calls on countries to prohibit certain forms of fisheries subsidies that contribute to overcapacity and overfishing, and Target 12.C makes a similar appeal to phase out "inefficient fossil fuel subsidies". The WTO has more stringent rules, or "hard law" on controlling subsidies in general, and the Agreement on Agriculture has stewarded a gradual reduction in the most trade-distorting support to the farming sector, but none of these address environmental effects specifically. At the global level, there are calls for streamlining positive renewable energy subsidies as well as involving global institutions like the WTO and the UNFCCC in the energy subsidy reform (Cosbey & Mavroidis 2014; Rubini 2012; De Bièvre 2017; van Asselt & Kulovesi 2017; Van de Graaf & van Asselt 2017).

Commonly cited obstacles for subsidy reform include concerns regarding impacts on competitiveness and distributional impacts, including employment. However, ex-post empirical analysis has found little evidence in this regard (OECD 2017c). Vested interests and political acceptability can also present barriers to subsidy reform. Political economy insights from successful biodiversity policy reform can shed light on how this transition can be achieved in practice (OECD 2017c). These suggest the need to: act quickly when presented with windows of opportunity that may be outside the influence of domestic policy makers and unrelated to the environment (for example, human health); build alliances between economic and environmental interests (e.g., when there are common interests between certain groups, even though the motivations may not be); devise targeted measures to address potential impacts on competitiveness and income distribution; build a robust evidence base on the social costs and benefits of reform; and encourage broad stakeholder engagement (OECD 2017c; 2011).

Finally, ensuring compliance with fair tax policies can help ensure funding for biodiversity and nature as well. Tax havens reduce the amount of financing available to governments for global public goods provisioning and provide bad actors with opportunities to avoid financial scrutiny, reducing the impact of policies such as certification or supply chain monitoring (also see section 6.3.2). A recent study of tax havens found that 70% of known fishing vessels implicated in illegal fishing are flagged in a tax haven, and that nearly 70% of foreign capital to the largest companies raising soy and beef in the Amazon, prime drivers of deforestation, was channeled through tax havens (Galaz *et al.*, 2018).

6.4.2 Addressing Over- and Under-consumption

Over-consumption by households is a major driver of resource use and depletion, primarily in housing, mobility and nutrition (Spangenberg & Lorek, 2002). Involuntary under-consumption is synonymous with poverty and a lack of options, while overconsumption results from unsustainable choices and practices. Overconsumption plays a major role in driving NCP loss and is associated with higher carbon footprints (Ivanova *et al.*, 2017). Reduced consumption is thus also an imperative to meet the Paris Agreement climate targets, which are unlikely to be met with resource efficiency or alternative energy sources alone (Alfredsson *et al.*, 2018). Patterns of over-consumption, however, vary greatly within and across global regions, with involuntary under-consumption and poverty representing the reality of a significant portion of the world population.

One basic misperception is that a better life is held to emerge from more consumption opportunities. Instead, studies show human needs are limited and mostly non-material; they can be satisfied with less resource consumption than usual in the affluent countries (Steinberge & Roberts, 2010) if suitable satisfiers are chosen (Max-Neef *et al.*, 1989). Satisfaction with GQL has been shown not to increase above a certain income threshold (Max-Neef 1995) and to be decoupled from income and thus consumption thereafter (Layard 2005; Hoffman & Lee 2016) (although the rich seem to be happier than the poor in most societies (Veenhoven 2010)).

Consumption-focused policies have a significant opportunity to complement other nature conservation efforts (Igoe 2013; Isenhour 2014) with a resource conservation potential of demand-side measures potentially matching supply side options (Cruetzig *et al.*, 2016; Lazarus *et al.*, 2011), in particular when combined with policies to compensate for rebound effects (the phenomenon where increased efficiency leads consumers to take that additional money and increase consumption elsewhere) (Jackson 2005; Lorek & Spangenberg 2014). We here review options for consumers, governments and the corporate sector.

Consumers' action options: Grassroots and civil society organizations have advocated a wide range of lifestyle modifications and shifts in consumer behaviours, often focusing on information and education initiatives for affluent and environmentally conscious consumers, such as generating pressures on corporations and governments by mobilizing the social norms of affluent consumers (Conroy 2001) and engaging in the co-designing of products and services (Fuad-Luke 2008). Critics point out that these successes are often short lived and have done little to challenge dominant consumption logics or practices. Furthermore, studies indicate that changing the composition of consumption has limited effects on the overall environmental impact (Røpke 2001) and that it is reducing the level of resource consumption that reduces drivers of environmental damage (Lorek 2010; di Giulio & Fuchs 2014; Lorek & Spangenberg 2014).

Already a number of consumers have chosen to reduce their consumption by practicing 'voluntary simplicity', often motivated more by lifestyle choices rather than concerns about sustainability (McDonald 2015) and in conjunction with reducing their income and increasing their leisure time and thus avoiding rebound effects (Freire-González *et al.*, 2017). As such changes are not easy in the current consumer society (Speck & Hasselkuss 2015), dedicated policies are called for to make a resource-light, good life easier (Schneidewind & Zahrnt 2014; Heindl & Kanschik 2016).

Government policy options supporting consumers: To influence *conscious decisions,* awareness-raising and information campaigns are viable options. However, the literature on their effectiveness is unclear, particularly for the average consumer who may not share strong environmental norms (Stern 2000; Spaargaren *et al.*, 2013). An option to influence *spontaneous decisions* is the choice architecture approach including nudging, i.e. offering pre-set default options which in some cases had a strong influence on consumers' propensity to make desirable choices (Gsottbauer & van den Bergh 2011). Nudges can include tailored messaging or offer peer comparisons, provide disclosures or warnings, create default rules, or use social norms (Sunstein 2015; Lehner *et al.*, 2015; Halker 2013; Olander & Thorgersen 2014). However, nudging has been effective only if the required change of everyday life routines and the effort required were not too onerous (Keller *et al.*, 2016). There is also very little evidence that non-regulatory measures used in isolation, including nudges, are effective for biodiversity conservation (Newton *et al.*, 2013; Hobson 2013). *Legislation and norms* have the advantage of binding all consumers for all kinds of decisions to the same standards, and to be implementable in relatively short time. They range from broad ecological tax reforms to bans of single-use disposable products, disincentives for travel or meat consumption, and public investments in product service agreements or collaborative consumption networks. Many consumers favor the removal of dangerous products from the market and a stronger role for governmental agencies in protecting consumers over more choice (Isenhour 2011).

Taxing consumption: Many taxes on activities or products exerting negative (and often indirect) effects on ecosystems and biodiversity rely either on the polluter-pay principle or on the user-pay principle (Ekins 1999). Examples of these "green" taxes and levies can include:

- Pesticide taxes, e.g. France, Denmark, Norway, Sweden, United States (OECD 2017a; Hogg *et al.*, 2014). However, moderate increases in the tax rate alone appear not to be sufficient to reduce use (Sainteny 2011; Jacquet *et al.*, 2011).
- Fee-based licenses for logging, fishing and hunting are price mechanisms to limit certain detrimental mechanisms (Fisher *et al.*, 2008).
- Taxes on luxury and consumer goods have shown some success in reducing excess consumption and raising money for other initiatives (Schor 2005).
- Road and congestion charges, often in large cities like London and Stockholm, have been shown to reduce transportation by single occupancy vehicles and lower carbon emissions (Newberry 2005).
- Carbon/energy/fuel taxes with the main motivation to mitigate climate change also reduce environmental risks and threats to ecosystems (Ekins 1999).
- Eco-VAT. In Brazil, an ecological value added tax is paid to municipal governments (Farley and Costanza 2010).

However, while these targeted fees and taxes, and VAT more generally, dampen consumption, very few direct consumption taxes have been designed specifically in order to preserve nature and NCP. Taxes can be combined with other economic instruments for these ends; for example, revenues from taxes may be used to finance other biodiversity-conserving activities, like protected areas (Farley and Costanza 2010; Raes *et al.*, 2016). As no global assessment of the effectiveness of these kinds of taxes is found in the literature, the evidence remains inconclusive (Hogg *et al.*, 2014). More empirical work on the experimental use of different taxation schemes and their environmental outcomes is recommended.

Local and regional governments across the world are also investing in a wide range of programs to encourage more resource-light consumption including elements of sufficiency such as hosting repair cafes, materials exchanges/swaps, and innovating 'collaborative consumption' events like tool lending libraries. Authorities have also indirect influences on consumption patterns and levels: public transport planning can enhance the accessibility without car use, with positive environmental and quality of life outcomes. Additionally, in most countries, public procurement is the single largest purchaser of goods and services. This gives public authorities from the local to international level the opportunity to strengthen sustainable suppliers and nudge others towards greening their offers, by stimulating the demand for energy saving buildings, recycled products or organic food, reducing the consumption of materials, energy and land and thus mitigating several direct and indirect drivers of nature deterioration (Brammer & Walker 2011; Lutz 2009).

Corporate action reducing consumption: Corporations and industry associations have responded to consumer demand through sustainable sourcing practices and consumer awareness campaigns in the interest of both resource protection and building brand loyalty. However, Williamson *et al.* (2006) found that such voluntary approaches will not alter the behaviour of manufacturing enterprises significantly unless they have a positive effect on the bottom line, e.g. by reducing resource or labor cost, ensuring employee morale (Jacobsen & Dulsrud 2007) or avoiding regulation by pre-empting measures (Marsden & Flynn 2000). The research on such Corporate Social Responsibility (CSR) programs tends to conceptual rather than empirical, except for some labelling and certification programs (Carlson *et al.*, 2018). See Supplementary Materials 6.6.1 for a detailed discussion on addressing overconsumption.

6.4.3 Reducing unsustainable production

Several studies have shown that production systems focused on economic growth correlate with increasing environmental impacts, both on micro/household and on macro/cross-national levels (Hayden & Shandra 2009; Rosnick & Weisbrot 2007; EEA 2014; Ward *et al.*, 2016). Policy options include the setting of resource caps and taxes, transitioning to a circular economy, corporate social responsibility, and using life cycle analysis as a policy support tool.

Resource caps and taxes: Resource caps and taxes are a way to limit the volume of resources used or produced in production processes. Examples with positive environmental effects include water extraction charges or energy sector charges (McDonald *et al.*, 2012), e.g., car fleet gasoline consumption limits as an obligation to manufacturers and public procurement. Caps and taxes support transformative change as reducing supply modifies the competition rules in a market economy, requiring companies to redesign products and business models by taking resource limitations (and implicitly biodiversity aspects) into account alongside economic considerations throughout the supply chain (Ayres 1989). A large number of studies have shown that avoidance costs tend to be lower than damage and repair costs (Aslaksen *et al.*, 2013; Gee *et al.*, 2013; Simberloff 2014, EEA 2017).

As one example, carbon pricing is currently in discussion as a possible way to spur development of non-fossil fuel energy sources and reduce carbon emissions (Essl & Mauerhofer 2018); a recent study found that while the potential to raise revenue from carbon pricing is highly variable depending on country's emission intensity and economic activity, many low income countries could finance much of their needs to implement the SDG with a carbon pricing scheme starting at $40/ton (Franks *et al.*, 2018). To avoid disproportionate negative effects on producers and resulting rises in prices, resource caps and taxes can be complemented with compensatory measures, such as carbon dividends and subsidies to low income energy users.

Transitioning to a circular economy: The major aim of the Circular Economy (CE) is to decouple economic growth and the deterioration of the environment (Ghisellini *et al.*, 2016), suggesting that economic prosperity and improved environmental quality can be achieved together at the same time (Kirchherr *et al.*, 2017) through technological, economic and social innovations (Jesus & Mendonça 2017). There are many competing definitions about what the circular economy is and how far it can be implemented at the micro (e.g. company, consumer), meso (e.g. industrial park) or the macro (regional, national, global) level (Kirchherr *et al.*, 2017). According to a frequently cited definition, CE is "an industrial system that is restorative or regenerative by intention and design. It replaces the ‹end-of-life› concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and within this, business models." (Ellen MacArthur Foundation 2013: p7). Most discussions about CE recognize that it may not be possible to make the economy fully circular. For example, **Figure 6.7** offers a representation of the CE that allows for raw materials input and residual waste outputs.

CE is promoted in various countries worldwide (for examples, see Supplementary Materials 6.6.2). Nevertheless, consensus is still lacking on how far the global economy is progressing towards a CE. Cooper *et al.* (2017) estimated that potential savings of energy used for economic activities worldwide could reach 6-11%, while Haas *et al.* (2015) carried out a material flows analysis on data from 2005 and estimated that the recycling within the economy as share of processed material reached 6%

Figure 6 7 **Depiction of the circular economy.**

Source: https://www.europarl.europa.eu/ireland/en/news-press/circular-economy-meps-call-for-“systemic-change”-to-address-resource-scarcity.

globally and 13% in the EU. Reasons for these relatively low numbers are thought to be the large proportion of non-recyclable fossil fuel and biomass material throughput (Haas *et al.*, 2015), and the accelerating production due to the rebound effect (Zink & Geyer 2017). Other factors include policy and enforcement failures, consumer preferences, costs, and infrastructure deficits (for details, see Supplementary Materials 6.6.2).

Corporate social responsibility (CSR): CSR initiatives are voluntary efforts by companies to address social and environmental concerns arising from business activities (Robinson 2011; European Commission 2011, Dyllick & Hockerts 2002; Baumgartner 2014; O'Connor & Spangenberg 2008). CSR is used by sectors that are directly affected by the degradation of local ecosystems and habitat loss (e.g. fisheries, agriculture, forestry, tourism) (Boiral & Heras-Saizarbitoria 2017; Hastings & Botsford 2003; Pickering & Hill 2007) as well as sectors that are indirectly affected through their globalized supply chains (Robinson 2011). The idea of CSR is that companies have the potential and responsibility to make a substantial contribution to arresting declines in biodiversity and ecosystems services (Armsworth 2010; Lambooy 2011; Athanas 2005; 'Biodiversity in Good Company' Initiative https://www.business-and-biodiversity.de/en/about-us/). The ultimate role of companies should be to identify, to be transparent and accountable for their impacts (ISO 26000) (ISO 2010), and to develop strategies to reduce negative and to maximize positive impacts. However, since the inception of the CBD in 1992, little progress has been achieved in terms of involving the business community in protecting biological diversity worldwide (Overbeek *et al.*, 2013). For instance, most of the Fortune 500 companies do not systematically record their activities regarding biodiversity and ecosystems service management (Bhattacharya, 2013); a recent study found only 5 companies in the Fortune 100 had specific and measurable commitments to biodiversity (Addison *et al.*, 2018). However, research suggests that business profits and good condition of biodiversity are often correlated (Tilman *et al.*, 2006; Worm & Barbier

2006; Bishop *et al.*, 2008; Lambooy 2011) (see also Supplementary Materials 6.6.2).

Using life cycle analysis as a policy support tool: Life cycle assessment (LCA) offers a method for quantitatively assessing and evaluating the inputs, outputs, and potential environmental impacts of a product system throughout its life cycle (ISO 2006a). It is widely applied by companies (Frankl & Rubik 2000; Clift & Druckman 2015) to inform consumers (Del Borghi 2013) and for public policy making (Owsianiak *et al.*, 2018). However, the inclusion of biodiversity in LCA has been limited to specific species or has related factors such as climate change or land use (Verones *et al.*, 2017; Goedkeep *et al.*, 2013; deBaan *et al.*, 2013; Schenk 2001; Penman *et al.*, 2010; Curran *et al.*, 2011; Koellner *et al.*, 2013; Souza *et al.*, 2015; Winter *et al.*, 2017; Chaundhary *et al.*, 2015; see Supplementary Materials 6.6.2). Several authors have discussed options to incorporate ecosystem services into LCA (Zhang *et al.*, 2010 a, b; Bakshi & Small 2011; Koellner & Geyer 2011; Cao *et al.*, 2015; Othoniel *et al.*, 2016; Blanco *et al.*, 2017; Bruel *et al.*, 2016) but so far with little progress. LCA approaches have a number of limitations, as they present many choices and assumptions, are complex and require sufficient and standardized data, provide a snapshot at a specific point in time which may be outdated by innovation or modified supply chains by the time the data is used, and focus on reducing the impacts per unit of consumption, not on reducing consumption levels themselves (Pré Consultants 2006; Finkbeiner 2014; Galatola & Pant 2014).

6.4.4 Reforming trade regimes to address disparities and distortions

Key global commodities with negative impacts on nature are among the major items traded internationally and subject to rules through the WTO and other regional and bilateral trade deals. There is growing evidence that these trading rules often encourage overproduction or unsustainable production, and that future markets can create pressures for expansion of production in unsustainable ways (Pace & Gephart 2017; Bruckner *et al.*, 2015). While challenging, it is increasingly acknowledged that reforming trade systems and financial markets is essential to controlling the impact of global economic drivers on nature.

Reforming the trade system: There are general concerns that trade liberalization contains considerable risks for nature and the environment. For example, tensions have been identified between WTO regulations, particularly the General Agreement on Tariffs and Trade (GATT) and environmental concerns. Documented cases focus on efforts to ban tuna from fisheries operations and nations that do not implement dolphin conservation measures (Waincymer 1998) or, similarly, to ban shrimp from fisheries operations and nations that do not implement turtle conservation measures (Benson 2003). Other examples include domestic support for multifunctional agriculture (see also 6.3.2) (Dibsen *et al.*, 2009; Hasund 2013, Potter & Burney 2002; Potter & Tilzey 2007). Tensions have also been identified between the GATT and biosecurity issues related to preventing diseases and invasive species from entering (Maye *et al.*, 2012).

A different issue identified in literature is related to the WTO Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) (Brand & Görg 2003). While the potential of WTO and other free trade agreements and WTO regulations to contribute to conservation and sustainability is criticized (Waincymer 1998; Brand & Görg 2003), some suggest that the inclusion of environmental provisions in TRIPS can prevent negative environmental impacts and even promote conservation and good environmental practices (Neumayer 2000; Ivanova & Angeles 2006). Opportunities within WTO have been identified in the Technical Barriers to Trade (TBT) agreements and in Preferential Trade Agreements (Charnovitz 2007). Also, the Geographical Indications (GI), part of TRIPS, can provide opportunities for conservation and sustainability, but only if nature and biodiversity friendly practices are embedded in the GI specification (Garcia *et al.*, 2007).

While other regional or bilateral free trade agreements such as NAFTA include environmental provisions, these have mostly been implemented in a narrow way and have not resulted in significantly raised levels of environmental protection (Sanchez 2002). At the global level, WTO has started to discuss environmental provisions as part of the Doha negotiations since 2001, but negotiations were not successful and ended in 2016. Since then, bilateral trade agreements have increased in importance, as have the intensification of 'trade wars'. The consequences of this situation for international cooperation, as well as for nature, its contributions and the quality of life are yet to be determined.

Reforming derivative and futures markets: The increasing trade in futures and derivatives over the past decade have been associated with outcomes that affect biodiversity. Futures and comparable financial products such as derivatives are essentially contracts between buyers and sellers of commodities that stipulate volumes, price and delivery date (Pollard *et al.*, 2008). Derivatives and futures turn variability into a credit risk that can be hedged against, traded, and speculated on, and signal the ongoing commodification of new forms of nature (Smith 2007; Cooper 2010). For example, climate and weather derivatives have emerged, seen as a flexible and cost-effective way for companies to reduce risk and become more creditworthy (Pryke 2007; Cooper 2010). While futures and derivatives contracts can offer potential income stability and protection against risks, they are also an opportunity for speculation and hedging on price movements which can lead to turbulence and price volatility (Cooper 2010). This means that, when unregulated, these markets can pose a potential threat to sustainability and contribute to social crises (Heltberg *et al.*, 2012).

In the United States, home to the largest commodity futures markets, financial regulations designed to prevent excessive levels of speculation by financial investors were in place for much of the 20th century. These rules included reporting requirements as well as 'position limits' that restricted the number of commodity futures contracts purely financial investors (also referred to as 'non-commercial operators') could hold at any given time. Over the course of the 1980s to early 2000s, these regulations were gradually relaxed (Clapp & Helleiner 2012). Following the deregulation of the US futures markets, speculative investment in agricultural commodities increased from US$ 65 billion in 2006 to US$ 126 billion in 2011 (Worthy 2011). It has been suggested that this contributed in part to the 2007-2008 food crisis, as a number of observers noted that food prices were rising more quickly and sharply than was warranted by the underlying fundamentals of supply and demand for those crops at the time (e.g., FAO 2008). Analysts identified speculative financial investment, including commodity index products marketed to large institutional investors, as a potential factor in driving up food prices (Masters 2008; Ghosh 2010) with severe impacts on the quality of life in many countries (Ivanic & Martin 2008; Bellemare 2015). Although there is debate over the extent to which financial speculators were responsible (see, for example, Sanders & Irwin 2010), several international organizations have noted that financial speculation in agricultural commodity markets can make food price trends more volatile (BIS 2011; UNCTAD 2011). Higher and more volatile food prices matter for biodiversity because when food prices rise, investment in agricultural production also typically rises, influencing land-use trends. At the height of food price volatility in the 2008-2013 period, there was a rush to increase production, especially of cereal crops such as wheat, maize and rice, as well as oil crops such as soy (FAO 2017).

As commodity exchanges around the world, including in developing countries, develop to include more sophisticated financial and investment products, it is important for them to consider adopting regulations that seek to limit excessive financial speculation on those markets that can affect biodiversity outcomes (FAO *et al.*, 2011): for example, by putting limits on the number of contracts per trader in each market (Ghosh *et al.*, 2012) and by enhancing market transparency (Clapp 2009; Minot 2014). In the wake of the 2008 financial crisis, governments around the world sought to tighten regulations on commodities futures markets with a view to reining in speculative financial investments that could affect prices and destabilize markets (Helleiner 2018). In the United States, the Dodd-Frank Wall Street Reform and Consumer Protection Act authorized the adoption of new rules to strengthen the position limits and reporting requirements to restrain excessive speculation. However, the substance of these rules has been weakened and their implementation has been delayed following extensive lobbying and court challenges from the financial industry. The European Union also developed more stringent regulations known as Mifid II, but these rules were also weakened in the face of the financial industry. It is unclear whether the new regulations in the US and EU, once fully implemented, will achieve their intended effect, and their subsequent impact on agricultural outcomes that affect biodiversity.

6.4.5 New models for a sustainable economy

In recent decades, many have questioned the economic growth paradigm and its compatibility not only with environmental sustainability but also achieving a good quality of life for all. The challenges of climate change and biodiversity loss, in particular, underline that the scale of economic activity has already pushed society out of the safe operating space of the planet (Rockström *et al.*, 2009; IPCC 2018). By detaching mainstream paradigms of unending economic growth from economic and social relations, alternative ways of understanding human and societal well-being have been proposed (Costanza *et al.*, 2014; Cattaneo 2014; O'Neill 2012). A central idea in these approaches is to decouple growth of the economy and enhancement of human well-being from resource use and extraction. The most prominent models are the Green Economy (also called Green Growth or Inclusive Green Growth, promoted by the OECD, UNEP and EU), which builds upon earlier discussion on ecological modernization (Mol & Spaargaren 2000), and the model of (physical) Degrowth leading to a steady state economy (Daly 1974; Denaria *et al.*, 2013).

The core assumption of the Green Economy model is that increasing economic activity as well as the generation of income and jobs can be achieved without becoming unsustainable. Key strategies in this endeavor include increasing the efficiency of resource use by means of technological and social innovations (York & Rosa 2003) and transitioning towards more sustainable patterns of consumption (UNEP 2002). Other discussions highlight the possibilities of substituting natural capital for human capital and human made capital (Pearce *et al.*, 1989; Pearce & Barbier 2000), while protecting a critical level of natural capital (Deutsch *et al.*, 2003; Ekins 2003).

The toolbox used in green economy policies typically includes a mix of regulatory (laws, voluntary agreements), economic or market based (green taxes, credits, certification, subsidies, offsetting, PES, circular economy) and informational instruments (labeling, consumer campaigns), with an emphasis on the latter two. On the consumption side, Green Economy strategies call for (voluntary) changes in consumption patterns towards the growth in production and consumption of non-material or non-resource intensive goods and services. There are however strong criticisms to this Green Economy concept arguing that the suggested measures may indeed be indispensable, but not sufficient in the long term and that more fundamental change is necessary (Victor 2008; Jackson 2009).

Degrowth, including the older idea of a steady state economy (Daly 1974), contests the necessity of economic growth as a condition of human well-being and good quality of life. Foremost amongst these is that for an economy to remain within ecological bounds, it must possess a constant stock of physical capital at a level that can be maintained by material flows remaining within the regenerative capacity of the ecosystem (Daly 1974). Only if economic output could be decoupled from resource use, growth in Gross Domestic Product (GDP) would be consistent with sustainability. Models of degrowth go beyond the physical steady state and advocate "an equitable downscaling of production and consumption that increases human well-being and enhances ecological conditions at the local and global levels, in the short and long-terms" (Schneider *et al.*, 2010:512). This implies reduced growth in the physical part of the economy and as a result in the monetary or financial side (Spangenberg 2010). On the consumption side, degrowth goes beyond greener consumption patterns by advocating for reduced consumption levels overall.

Strategies for degrowth include limits on resource extraction, new social security guarantees and work-sharing (reduced work hours); universal basic income and income caps (see Supplementary Materials 6.6.3); consumption sufficiency, and resource taxes with affordability safeguards; redistribution of wealth, support of innovative models of "local living"; commercial and commerce free zones; new forms of money; high reserve requirements for banks; ethical banking; green investments; cooperative property and cooperative firms (Eckersley Ro 2006; Jackson 2009; Korten 2008; Latouche 2009; Spangenberg 2010; Klitgaard & Krall 2012; Heikkurinen 2016; Samerski 2016). Already existing practices that adopt these models or parts include eco-communities and villages, cooperatives, community currencies, time banking or urban gardening (e.g., Cattaneo & Gavaldà 2010; Nierling 2012; 2010; Dittmer 2013; Xue 2014; LeBlanc 2017; McGuirk 2017). In a degrowth strategy, these practices are integrated with selected instruments from the green economy toolbox, like green taxes or consumer campaigns (Kallis *et al.*, 2012; Rigon 2017), but not others such as biodiversity banking due to reservations against the commodification of nature (Gómez-Baggethun & Ruiz-Pérez 2011).

Evidence of the effectiveness of alternative models of the economy, including associated strategies and practices, is inconclusive. Yet, existing evidence shows that current strategies and practices have not accomplished a decoupling of economic growth from energy and materials consumption over an extended time span (chapter 2). Without an adjustment of orientations and priorities, including an effective instrumentation of such policies, a sustainable economy is not going to be achieved. These alternative models and associated strategies and practices offer opportunities to promote nature and its contributions, recognize value pluralism (Pascual *et al.*, 2017), and enhance inclusiveness as recognized in the SDG. An example of such a value pluralist approach is the concept of Good Living ("Buen Vivir"), which means material, social and spiritual well-being of people who live not at the cost of others or nature (Brand *et al.*, 2017; Beling *et al.*, 2018). This concept of Good Living has been adopted in the Bolivian constitution, calling for recognition of the rights of nature and holistic understanding (IPBES 2016; Pacheco 2014a, b), albeit with limited impact on the country's neo-extractivist policy (Beling *et al.*, 2018). Other examples include the broad discussion on the transition to an "ecological civilization" in China (Yan & Spangenberg 2018).

Since the GDP does not capture the state of the environment, biodiversity nature and its contributions, and is not a measure of welfare in itself, the discussion of alternative models of the economy has extended to the development of alternative measures to represent human well-being and good quality of life (see chapter 2). Some, like the Index of Sustainable Economic Welfare (ISEW) (Daly & Cobb 1989) and the Genuine Progress Indicator (GPI) (Cobb *et al.*, 1995), are based on GDP calculation; subtracting the "bads" like environmental degradation and biodiversity loss in monetary terms and adding the "goods" not included in the GDP such as the value of unpaid work. A comprehensive set of indicators for short and longer-term development has been suggested by the Stiglitz-Sen-Fitoussi Commission set up by the French government (Stiglitz *et al.*, 2010). Another prominent measure is the Gross National Happiness Index, introduced by the Bhutanese Government. This measure focuses on equitable social development, cultural preservation and conservation of the environment (Verma *et al.*, 2017). Recently, local, regional and national governments, including different States in the US (see Talberth & Weisdorf 2017 for an overview), and Belgium (Bleys 2013) have shown interest in these measures.

Further innovations have been proposed in accounting systems to incorporate environment and ecosystems. To this end, UN Statistics extended the international statistical system by satellite accounts of physical flows and environmental goods, and in its latest version the value of ecosystems and their services (https://seea.un.org/). This includes amongst others Material Flow Accounting (MFA) and Material and Energy Flow Accounting (MEFA) (Bringezu *et al.*, 1997; Haberl *et al.*, 2004) and Natural Capital (NC) assessment and accounting (Natural Capital Coalition 2017). There is a wide variety in methods and approaches. Some of these focus on only one ecosystem service or form of capital (for example carbon), some use formal accounting methods and involve monetization, and again others use non-monetary units to quantify and express environmental stocks and flows (Day 2013; Faccoli *et al.*, 2016; Bateman *et al.*, 2011; Donnely *et al.*, 2016; Agrawala *et al.*, 2014; Robèrt 2002; Schmidt-Bleek 2008; Spangenberg *et al.*, 1998; Dittrich *et al.*, 2012; Ulgiati *et al.*, 2011, Ayres *et al.*, 1996; Steen-Olsen *et al.*, 2012; Giampietro *et al.*, 2014; Lomas & Giampietro 2017; ten Brink 2012; UNU-UHDP and IHDP 2014) (see Supplementary Materials 6.6.3).

There is as yet no evidence of the effectiveness of the use of environmental accounting approaches. As an information instrument, its effectiveness is based on the premise that more information will result in better decision-making (Guerry *et al.*, 2015; Mace *et al.*, 2015) – a premise that is largely unsupported (Caceres *et al.*, 2016; Turnhout *et al.*, 2013; Wesselink *et al.*, 2013). Yet, as has been shown for other information tools such as models or indicators (Turnhout *et al.*, 2007; Van Egmond & Zeiss 2010; see Section 6.2.2), environmental accounting may be helpful as a tool for the facilitation of dialogue on the diverse values of nature and biodiversity. However, in order to enable this role, it is important that it uses a broad perspective that includes non-economic values and that it employs a participatory approach so that relevant stakeholders can contribute to the definition and identification of indicators for nature, ecosystem services, environmental assets, and natural capital (Turnhout *et al.*, 2007; Raymond *et al.*, 2009).

6.4.6 Conclusions

The existing economic system of capital-intensive exploitation of nature, extensive international trade and their telecouplings, and wide-ranging inequality between countries and between peoples within countries, is not a system that is natural or to which there is no alternative. To the contrary, such an economic system has evolved over time due to human interventions, institutions, policy choices and options, and as such, can be transformed just as it was created. The problem is often one of both recognizing the scope of the problem through sharing information, implementing more inclusive and realistic economic accounting, as well as tackling reforms to the system through gradual incremental changes like changing consumer behaviour, incentivizing different economic pathways, reducing production impacts, and reforming trade, subsidies and markets or various kinds. More transformative options like creating circular economies, moving to degrowth and steady-state economic paradigms, tackling inequality, and revamping the way we finance and prioritize conservation of nature and biodiversity will require concerted efforts from a range of decision makers, with national governments, private corporations and international institutions leading the way. Designing such an integrated world economy that values nature and its contributions in pluralistic ways, recognizes their long-term importance to human quality of life, and rightfully prioritizes them as public goods above private profit is a long-term vision that will require innovative, imaginative and adaptive ways to transform our current economic and governance systems.

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ANNEXES

ANNEX I
Glossary

A

Abundance
The size of a population of a particular life form (IPBES, 2016).

Abyssal plain
An extensive level area of the deep ocean floor typically situated between the foot of the continental rise or mid-ocean ridge and an oceanic trench and covered with fine sediments.

Access and benefit sharing (ABS)
Access and benefit-sharing (ABS) refers to the way in which genetic resources may be accessed, and how the benefits that result from their use are shared between the people or countries using the resources (users) and the people or countries that provide them (providers). In some cases, this also includes valuable traditional knowledge associated with genetic resources that comes from Indigenous Peoples and Local Communities. The benefits to be shared can be monetary, such as sharing royalties when the resources are used to create a commercial product, or non-monetary, such as the development of research skills and knowledge (Convention on Biological Diversity, 2002, 2010a, 2010b).

Acidification
Ongoing decrease in pH away from neutral value of 7. Often used in reference to oceans, freshwater or soils, as a result of uptake of carbon dioxide from the atmosphere (see 'Ocean acidification' for a specific definition).

Adaptability (part of resilience)
The capacity to adjust responses to changing external drivers and internal processes, and thereby channel development along the preferred trajectory in what is called a stability domain (Walker *et al.*, 2004).

Adaptive capacity
The general ability of institutions, systems, and individuals to adjust to potential damage, to take advantage of opportunities, or to cope with the consequences (Millenium Ecosystem Assessment, 2005).

Adaptive management
A systematic process for continually improving management policies and practices by learning from the outcomes of previously employed policies and practices. In active adaptive management, management is treated as a deliberate experiment for purposes of learning (Millenium Ecosystem Assessment, 2005).

Adaptive radiation
The evolution of a number of divergent species from a common ancestor, each species becoming adapted to occupy a different ecological niche (Lawrence, 2005).

Aerosol
A collection of solid or liquid particles suspended in a gas. They include dust, smoke, mist, fog, haze, clouds, and smog (Hinds, 1999).

Afforestation
Planting of new forests on lands that historically have not contained forests (IPCC, 2014a).

Agricultural extensification
The process of low and/or decreasing the use of capital and inputs (e.g., fertilisers, pesticides, machinery, labour) relative to land area (EUROSTAT, 2018a).

Agricultural intensification
The process of increasing the use of capital, labour, and inputs (e.g., fertilisers, pesticides, machinery) relative to land area, to increase agriculture productivity (EUROSTAT, 2018b).

Agrobiodiversity
Agricultural biodiversity includes all components of biological diversity of relevance to food and agriculture, and all components of biological diversity that constitute the agricultural ecosystems, also named agro-ecosystems: the variety and variability of animals, plants and micro-organisms, at the genetic, species and ecosystem levels, which are necessary to sustain key functions of the agro-ecosystem, its structure and processes (Convention on Biological Diversity, 2000).

Agroecology
The science and practice of applying ecological concepts, principles and knowledge (i.e., the interactions of, and explanations for, the diversity, abundance and activities of organisms) to the study, design and management of sustainable agroecosystems. It includes the roles of human beings as a central organism in agroecology by way of social and economic processes in farming systems. Agroecology examines the roles and interactions among all relevant biophysical, technical and socioeconomic as well as sociopolitical components of farming systems and their surrounding landscapes.

Agroecosystem
An ecosystem, dominated by agriculture, containing assets and functions such as biodiversity, ecological succession and food webs. An agroecosystem is not restricted to the immediate site of agricultural activity (e.g., the farm), but rather includes the region that is impacted by this activity, usually by changes to the complexity of species assemblages and energy flows, as well as to the net nutrient balance.

Agroforestry
Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as other agricultural crops and animals, in some form of spatial arrangement or temporal sequence (Choudhury & Jansen, 1999). For spatial quantification purposes, agroforestry has been defined on the basis of the percentage of tree cover on agricultural land, such as above 10% in Zomer *et al.* (2009).

Albedo
The fraction of solar radiation reflected by a surface or object, often expressed as a percentage (IPCC, 2014a).

Alpha diversity
The diversity of species within a particular area or ecosystem, expressed by the number of species (species richness) present there (Park, 2007).

Animism
A nature-culture ontology that is defined by the fact that humans acknowledge that non-humans have a different physicality or external appearance but that non-humans have an inner self that is similar to humans, which allows exchanges and relationships that may be conflictual or reciprocal.

Anoxic event
Extreme coastal hypoxic conditions (dissolved oxygen <0.5mL per liter), leading to "dead zones" with mass mortality of benthic fauna (Altieri *et al.*, 2017; Diaz & Rosenberg, 2008).

Anthrome
A shortened form for 'anthropogenic biome', also known as 'human biome'. Describes the contemporary, human-altered form of biomes. Transformation to an anthrome occurs where people capture one or more nature's contributions to people into anthropogenic pathways to a high degree. The four IPBES anthromes are broader and more aggregated than many formally described anthromes. Since anthromes are transformed parts of a biome, the pre-transformation extent of the biome may be relevant for analysis (Alessa & Chapin III, 2008; Ellis & Ramankutty, 2008).

Anthropocene
A proposed term for the present time interval, which recognizes humanity's profound imprint on and role in the functioning of the Earth system. Since it was first proposed in 2000 (Crutzen, 2002; Crutzen & Stoermer, 2000), the term has evolved in breadth and diversely, now ranging from a proposed definition of a new geological epoch, a widely-used metaphor for global change, a novel analytical framework, a meme about the relationship of society to nature, and the framing for new and contested cultural narratives. Different starting periods have been proposed for the geological definition of the Anthropocene, including early agriculture and domestication, colonial species exchange, the onset of the industrial revolution, nuclear bomb deployment in 1945, and the post-WWII period characterized by the great acceleration of global changes and the spread of techno-fossils (Brondizio *et al.*, 2016). A proposal to formalize the 'Anthropocene' as a defined geological unit within the Geological Time Scale remains under discussion by the 'Anthropocene' Working Group for consideration by the International Commission on Stratigraphy (IUGS, 2018).

Anthropocentric
Anthropocentric qualifies an action or a perception of a given situation that is interpreted by humans or consider humans as the main focus. Nature's contributions to people are fundamentally anthropocentric.

Anthropogenic assets
Built-up infrastructure, health facilities, or knowledge - including indigenous and local knowledge systems and technical or scientific knowledge - as well as formal and non-formal education, technology (both physical objects and procedures), and financial assets. Anthropogenic assets have been highlighted to emphasize that a good quality of life is achieved by a co-production of benefits between nature and people.

Anthropogenic biome
See 'Anthrome'.

Anthropogenic landscapes
Areas of Earth's terrestrial surface where direct human alteration of ecological patterns and processes is significant, ongoing, and directed toward servicing the needs of human populations for food, shelter and other resources and services including recreation and aesthetic needs (Ellis *et al.*, 2006).

Aquaculture
The farming of aquatic organisms, including fish, mollusks, crustaceans and aquatic plants, in both inland and coastal areas, and involving some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated (FAO, 1997).

Archetype
In the context of scenarios, an over-arching scenario that embodies common characteristics of a number of more specific scenarios.

Article 8(j) of the CBD
Article 8(j) states that each contracting Party of the Convention on Biological Diversity shall, as far as possible and as appropriate, subject to national legislation, respect, preserve and maintain knowledge, innovations and practices of indigenous and local communities embodying traditional lifestyles relevant for the conservation and sustainable use of biological diversity and promote their wider application with the approval and involvement of the holders of such knowledge, innovations and practices and encourage the equitable sharing of the benefits arising from the utilization of such knowledge innovations and practices (Convention on Biological Diversity, 1992).

Average genetic variation (heterozygosity)
The condition of having two different alleles at a gene locus (Allendorf, 2014).

Avoided deforestation in conjunction with afforestation and reforestation (ADAFF)
Land-based climate change mitigation strategy based on maintaining and expanding global forest area, and thus the carbon uptake of forest ecosystems in biomass and soil (Krause *et al.*, 2017).

B

Basal area
Area occupied by the cross-section of tree trunks and stems at base height (130cm from the ground). It is used to characterize different variables in forest ecology and management, e.g., forest structure, productivity and growth rate (Faber-Langendoen & Gentry, 1991).

Benefit sharing
Distribution of benefits between stakeholders.

Benthic
Occurring at the bottom of a body of water; related to benthos (NOAA, 2018b).

Biocentric worldview
Ethical perspective holding that all life (including humans, fauna, flora and domestic animals) deserves equal moral consideration or has equal moral standing (DesJardins, 2013). It contrasts with worldviews characterized as anthropocentric, which places humans at the center.

Biochemical oxygen demand (BOD)
A measure of the amount of oxygen required or consumed for the microbiological decomposition (oxidation) of organic material in water. The purpose of this indicator is to assess the quality of water available to consumers in localities or communities for basic and commercial needs. It is also one of a group of indicators of ecosystem health (United Nations, 2007).

Biocultural approaches to conservation / biocultural conservation
Conservation actions made in the service of sustaining the biophysical and sociocultural components of dynamic, interacting, and interdependent social–ecological systems (Gavin *et al.*, 2015).

Biocultural diversity
Biocultural diversity is considered as biological and cultural diversity and the links between them (CBD, 2018b).

Biodiversity
The variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part. This includes variation in genetic, phenotypic, phylogenetic, and functional attributes, as well as changes in abundance and distribution over time and space within and among species, biological communities and ecosystems.

Biodiversity conservation
The management of human interactions with genes, species, and ecosystems so as to provide the maximum benefit to the present generation while maintaining their potential to meet the needs and aspirations of future generations; encompasses elements of saving, studying, and using biodiversity (WRI *et al.*, 1992).

Biodiversity hotspot
A generic term for an area high in such biodiversity attributes as species richness or endemism. It may also be used in assessments as a precise term applied to geographic areas defined according to two criteria (Myers *et al.*, 2000): (i) containing at least 1,500 species of the world's 300,000 vascular plant species as endemics, and (ii) being under threat, in having lost 70 % of its primary vegetation.

Biodiversity Intactness Index
An indicator of the average abundance of a large and diverse set of organisms in a given geographical area, relative to their reference populations (Scholes & Biggs, 2005).

Biodiversity offset
Measurable conservation outcomes resulting from actions designed to compensate for significant residual adverse biodiversity impacts arising from development plans or projects after appropriate prevention and mitigation measures have been taken. The goal of biodiversity offsets is to achieve no net loss and preferably a net gain of biodiversity on the ground with respect to species composition, habitat structure, ecosystem function and people's use and cultural values associated with biodiversity (UNDP, 2016a).

Bioenergy
Energy generated by combusting solid, liquid or gas fuels made from biomass feedstocks, which may or may not have undergone some form of conversion process (Committee on Climate Change, 2011).

Bioenergy in combination with carbon capture and storage (BECCS)
Land-based climate change mitigation strategy involving the planting of bioenergy crops or trees, which are burned in power stations or converted to biofuels, and the released CO_2 being captured for long-term underground storage in geological reservoirs (Krause *et al.*, 2017).

Bioethanol
See 'Biofuel'.

Biofuel
Liquid, solid, or gaseous fuel produced by conversion of biomass. Examples include bioethanol from sugar cane or corn, charcoal or woodchips, and biogas from anaerobic decomposition of wastes (OECD, 2002).

Biogas
See 'Biofuel'.

Biogenic volatile organic compounds (BVOC)
Compounds that include organic atmospheric trace gases other than carbon dioxide and carbon monoxide; isoprenoids (isoprene and monoterpenes) are among the most prominent BVOC emitted (Kesselmeier & Staudt, 1999).

Biogeochemical cycles
Biogeochemical cycles involve the fluxes of chemical elements among different parts of the Earth: from living to non-living, from atmosphere to land to sea, and from soils to plants (Galloway *et al.*, 2014).

Biological conservation
See also 'Biodiversity conservation'. Application of science to conservation problems addressing the biology of species, communities and the ecosystem that are perturbed either directly or indirectly by human or other agents. Its goal is to provide principles and tools for preserving biological diversity. The branch of biology that deals with threats to biodiversity and with preserving the biologic and genetic diversity of animals and plants (Soulé, 1985).

Biological Oxygen Demand (BOD)
See 'Biochemical Oxygen Demand (BOD)'.

Biological pump
The fixation of carbon at the oceans' surface by photosynthesizing organisms and subsequent sinking of a sizable fraction (15–20%) of total productivity creates a strong vertical transport that dominates the distribution of carbon, nutrients, and oxygen in the ocean, known as the 'biological pump' (Ridgwell, 2011).

Biological resources
Biological resources includes genetic resources, organisms or parts thereof, populations, or any other biotic component of ecosystems with actual or potential use or value for humanity (Convention on Biological Diversity, 1992).

Biomass (ecology)
The mass of non-fossilized and biodegradable organic material originating from plants, animals and micro-organisms in a given area or volume.

Biomass (for production)
Biological material that can be used as fuel or for industrial production. Includes solid biomass such as wood, plant and animal products, gases and liquids derived from biomass, industrial waste and municipal waste (US Energy Information Administration, 2018).

Biome
A set of naturally occurring communities of plants and animals occupying an environmental and/or climatic domain, defined on a global scale. IPBES biomes (e.g., tropical and subtropical forests, shelf ecosystems, inland waters) are broader and more aggregated than many purely biological classification systems. Where biomes are transformed into anthromes, the pre-impact range of the biome may still be relevant for analysis. 'Natural biome' may be used to distinguish from 'anthropogenic biome' or 'anthrome'.

Bioprospecting
The purposeful evaluation of plant and animal biological material in search of valuable new products (Artuso, 2002).

Biosphere
The part of the Earth system comprising all ecosystems and living organisms, in the atmosphere, on land (terrestrial biosphere) or in the oceans (marine biosphere), including derived dead organic matter, such as litter, soil organic matter and oceanic detritus (IPCC, 2014a).

Biotechnology
Any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use (Convention on Biological Diversity, 1992).

Blue carbon
The carbon stored in marine and coastal ecosystems (Howard *et al.*, 2014).

Bottom-up control of the food web
A mode of control of trophic interactions by resources, in which organisms on each trophic level are food limited, as opposed to a top-down control (by predators), in which organisms at the top of food chains are food limited, and at successive lower levels, they are alternately predator, then food limited (Power, 1992).

Buen vivir
There is no single definition of Buen Vivir. Generally, it refers to an alternative to economic development-centered approaches, generally defined as forming part of the Andean indigenous cosmology, based on the belief that true wellbeing is only possible as part of a community in a broad sense, including people, nature and the Earth, linked by mutual responsibilities and obligations, and that the wellbeing of the community is above that of the individual.

Buffer (ecology)
A natural or anthropogenic feature which separates land uses.

Buffer zones (protected areas)
Areas between core protected areas and the surrounding landscape or seascape which protect the network from potentially damaging external influences and which are essentially transitional areas (Bennett & Mulongoy, 2006).

Burden
The resulting negative impacts of ecosystem use and management on people and nature, including distant, diffuse and delayed impacts (modified from Pascual *et al.*, 2017)

By-catch
The incidental capture of non-target species. The portion of a commercial fishing catch that consists of marine animals caught unintentionally (Merriam-Webster, 2015).

C

C3 photosynthesis
The major of the metabolic pathways for CO_2 fixation by plants, involving a 3-carbon organic intermediate molecule. C3 photosynthetic plants possess a specific leaf structure, and are not adapted to non-optimal conditions(Nature, 2018a).

C3 plants
Plants that use C3 photosynthesis to capture CO_2 (New South Wales Government, 2018).

C4 photosynthesis
C4 photosynthesis is an evolved metabolic mechanism for plant carbon fixation, in which atmospheric CO_2 is first incorporated into a 4-carbon intermediate molecule. It allows for a more efficient process compared to C3 photosynthesis, especially in non-optimal water availability conditions and in the presence of high solar radiation (Nature, 2018b).

C4 plants
Plants that use C4 photosynthesis to capture CO_2. The Poaceae family (grasses) accounts for about half of the C4 species (New South Wales Government, 2018; Osborne *et al.*, 2014).

Cap-and-trade
An economic policy instrument in which the State sets an overall environmental target (the cap) and assigns environmental impact allowances (or quotas) to actors that they can trade among each other.

Carbon cycle
The flow of carbon (in various forms, e.g., as carbon dioxide (CO_2)) through the atmosphere, ocean, terrestrial and marine biosphere and lithosphere (IPCC, 2014a).

Carbon footprint
A measure of the emission of gases that contribute to heating the planet in carbon dioxide (CO_2)-equivalents per unit of time or product; there is no universally-accepted definition of the term (Ercin & Hoekstra, 2012).

Carbon sequestration
The long-term storage of carbon in plants, soils, geologic formations, and the ocean. Carbon sequestration occurs both naturally and as a result of anthropogenic activities.

Carbon sink
Any process, activity or mechanism that removes carbon dioxide from the atmosphere (IPCC, 2014a).

Carbon uptake
See 'Carbon sequestration'

Carrying capacity
In ecology, the carrying capacity of a species in an environment is the maximum population size of the species that the environment can sustain indefinitely. The term is also used more generally to refer to the upper limit of habitats, ecosystems, landscapes, waterscapes or seascapes to provide tangible and intangible goods and services (including aesthetic and spiritual services) in a sustainable way.

Certification (environmental)
A procedure by which a third party gives written assurance that a product, process or service is in conformity with certain environmental standards (Dankers & Liu, 2003).

Certification principles and standards
A list of principles that certification schemes need to satisfy in order to be effective and credible.

Charismatic species
Any species that has popular appeal and is used to focus attention on conservation campaigns (Froese & Pauly, 2018).

Chemosynthesis
Synthesis of organic compounds (as in living cells) by energy derived from inorganic chemical reactions.

Circular economy
A regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling (Geissdoerfer *et al.*, 2017).

Citizen science
Citizen science refers to research collaborations in which volunteers and scientists partner to answer real-world questions, typically through a connected interface. A major setback of citizen science

projects is that they may require some level of computer literacy and network connectivity, both rare in many rural areas of the world. Despite the challenge, some researchers have already been successful in implementing interactive multimedia web-based tools for the collection of data based on local monitoring systems (Ens, 2012; Gill & Lantz, 2014; Pulsifer *et al.*, 2010; Stevens *et al.,* 2014).

Clade
A group of organisms believed to comprise all the evolutionary descendants of a common ancestor (Oxford Living Dictionaries, 2018).

Climate change
A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC, 2014a) (please see related definition for human-induced climate change below).

Collapse (social-ecological system)
The rapid and durable loss of a defined social-ecological system as such, resulting in substantial loss of social-ecological capital (e.g., biomass) (Cumming & Peterson, 2017).

Co-management
Process of management in which government shares power with resource users, with each given specific rights and responsibilities relating to information and decision-making (OECD, 2007b).

Community (ecological)
An assemblage of populations of at least two different species which coexist, and to various degrees interact directly and indirectly within a defined local geographic area and in a particular time; it is characterized in terms of taxonomic and functional composition (the species and functional types present) and richness (e.g., richness, abundance, dominance and distribution of species, or phenotypes) (Stroud *et al.*, 2015).

Community forestry
A broad term used to describe models of forest management that give local users the majority say in making decisions. Similar terms include participatory forest management, collaborative forest management, social forestry, and community-based forest management. With an aim to reduce poverty, community forestry is participatory and is intended to serve all community members equitably.

Community-based conservation
Institutions and/or processes involving community members in the protection of biodiversity aimed at promoting the coexistence of people and nature. This includes -but is not restricted to- Indigenous Peoples' and rural and coastal community conserved territories and areas (see 'ICCAs') (Western *et al.*, 1994).

Community-based monitoring
Processes involving the participation of community members in a range of observation and measurement activities to maintain awareness of ecological and social factors affecting a community (Bliss *et al.*, 2001).

Community-based natural resource management
A process by which local groups or communities organize themselves with varying degrees of interaction with state agencies and outside support so as to apply their skills and knowledge to the care of natural resources while satisfying livelihood needs (Pretty & Gujit, 1992).

Community-managed forests
Decentralized system of forest resource management designed to promote more equitable outcomes for stakeholders' livelihoods changing relationships between stakeholders, government agencies, and markets (adapted from Newton *et al.*, 2015).

Conservation agriculture
An approach to managing agroecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. It is characterized by three linked principles, namely: 1) continuous minimum mechanical soil disturbance; 2) permanent organic soil cover; and 3) diversification of crop species grown in sequences and/or associations. This covers a wide range of approaches from minimum till to permaculture and "mimicking nature".

Conservation benefits
The positive impacts on people and ecosystems due to conservation.

Conservation biology
The branch of biological science concerned with the conservation, management, and protection of vulnerable species, populations, and ecosystems. Also see 'Biological conservation'.

Continental shelf
The gently sloping, shelf-like part of the seabed adjacent to the coast extending to a depth of about 200m (IUCN, 2012a).

Continental slope
The often steep, slope-like part of the seabed extending from the edge of the continental shelf to a depth of about 2,000m (IUCN, 2012a).

Co-production (of contributions between nature and people)
In the context of the IPBES conceptual framework, this is the joint contribution by nature and anthropogenic assets in generating nature's contributions to people (IPBES, 2016).

Coral bleaching
When water is too warm, corals will expel the algae (zooxanthellae) living in their tissues causing the coral to turn completely white. Corals can survive a bleaching event, but they are under more stress and are subject to mortality (NOAA, 2018d).

Corridor / biological corridor
A geographically defined area which allows species to move between landscapes, ecosystems and habitats, natural or modified, and is intended to ensure the maintenance of biodiversity and ecological and evolutionary processes.

Cosmic models
A vision of reality that places the highest importance or emphasis in the universe or nature, as opposite to an anthropocentric vision, which strongly focuses on humankind as the most important element of existence.

Cosmologies (or cosmogonies)
The ways any society develops worldviews that aim at explaining the content and the dynamics of the universe, its spatial and temporal properties, the types of living beings that inhabits it, the principles and energies that explains its origin and its future.

Country of origin of genetic resources
Country possessing genetic resources in *in situ* conditions (Convention on Biological Diversity, 1992).

Country providing genetic resources
Country supplying genetic resources collected from *in situ* sources, including populations of both wild and domesticated species, or taken from *ex situ* sources, which may or may not have originated in that country (Convention on Biological Diversity, 1992).

Crop wild relative
See 'Wild relative'.

Cross-pollination
The movement of pollen between the flowers of two distinct plants (IPBES, 2016).

Cryosphere
The components of the Earth system that contain a substantial fraction of water in a frozen state, i.e., sea ice, glaciers, ice sheets (National Snow and Ice Data Center (NSIDC), 2018).

Cultural change (or culture change)
Cultural change is a continuous process in any society, which can vary from gradual to stochastic, resulting from interactions between processes that are internal (e.g., needs, local changes, crisis, mobility, ideas, invention and innovation, conflicts, etc.) and external (e.g., diffusion, external agents, political and economic forces, conflicts, etc.) (Berry, 2008; Redfield *et al.*, 1936). Cultural change is interpreted differently depending on theoretical orientation, such as diffusionism, modernization theory, world system theory, neocolonialism, globalization, among others (see Peña, 2005; Rudmin, 2009; Santos-Granero, 2009). Culture change can be selective or systemic and most often involves resistance and conflicts but can also lead to adaptation and resilience in changing contexts and environments.

Cultural ecosystem services
A category of ecosystem services first developed in the Millenium Ecosystem Assessment (2005) to refer to the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience, including, e.g., knowledge systems, social relations, and aesthetic values (Millenium Ecosystem Assessment, 2005). In the Global Assessment, cultural ecosystem services are included as part of both material and non-material nature's contributions to people (see chapter 1).

Cultural keystone species / culturally important species
The culturally salient species that shape in a major way the cultural identity of a people, as reflected in the fundamental roles these species have in diet, materials, medicine, and/or spiritual practices (Garibaldi & Turner, 2004).

Cultural landscapes
Cultural landscapes express the long-term co-evolution relationships between people and nature, influenced by internal and external forces affecting the aesthetic and productive configuration of land management, water bodies, wildlife, property systems, infrastructure and human settlements, and which are both a source and a product of changing social, institutional, economic, and cultural systems (also see WHC, 2008).

Cultural values
Cultural values are shared social values and norms, which are learned and dynamic, and which underpin attitudes and behaviour and how people respond to events and opportunities, and affects the hierarchy of values people assign to objects, knowledge, stories, feelings, other beings, forms of social expressions, and behaviours.

Culture
There is no single definition of culture. A commonly accepted definition of culture refers to the system of shared beliefs, values, customs, behaviours, and artifacts, and the meanings attributed to them, that the members of society use to cope and interact with the world and one another, and that are transmitted from generation to generation through learning (Bates & Plog, 1990).

Customary land tenure
The socially-embedded systems and institutions used within communities to regulate and manage land use and access, and which derive from the community itself rather than from the state.

Customary law
Law consisting of customs that are accepted as legal requirements or obligatory rules of conduct; practices and beliefs that are so vital and intrinsic a part of a social and economic system that they are treated as if they were laws (CBD, 2018b).

Customary rights
Rights, such as land rights or political rights, that are granted by either customary or statutory law. Customary rights exist where there is a consensus of relevant actors considering them to be 'law'.

Customary sustainable use
Uses of biological resources in accordance with traditional cultural practices that are compatible with conservation or sustainable use requirements (CBD, 2018b).

D

Deforestation
Human-induced conversion of forested land to nonforested land. Deforestation can be permanent, when this change is maintained and definitive, or temporary when this change is part of a cycle that includes natural or assisted regeneration.

Degraded lands
Land in a state that results from persistent decline or loss of biodiversity and ecosystem functions and services that cannot fully recover unaided within decadal timescales.

Demographic transition
A model describing transition in demographic profile of a population, which has been associated with the development process that transforms an agricultural society into an industrial one and characterized by a rapid population growth due to a decline in the death rate while fertility remains high initially; the growth rate then declines due to a decline in the birth rate. Before the transition's onset, population growth is low as high death rates tend to offset high fertility. After the transition, population growth is again below replacement level as both birth and death rates reach low levels (Bongaarts, 2009).

Denitrification
The reduction of nitrates and nitrites to nitrogen by microorganisms.

Deoxygenation (ocean)
Decreased oxygen concentrations in the ocean, as a result of climate change and other anthropogenic stressors, e.g., nutrient input due to inefficient fertilizer use (Isensee & Valdes, 2015).

Desertification
Desertification means land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities. Desertification does not refer to the natural expansion of existing deserts (UNCCD, 2014).

Dispersal
Movement of individuals (and in some species, their gametes) that has the potential for moving genes through space (Templeton, 2017).

Domesticated species
Species in which the evolutionary process has been influenced by humans to meet their needs (Convention on Biological Diversity, 1992).

Domestication
Evolutionary process driven by human (whether conscious or unconscious) selection but also involving natural processes applied to wild plants or animals and leading to adaptation to cultivation and consumption or utilization. Domestication can be complete, whereby organisms become entirely dependent on humans for their continued existence or can be partial or incipient, whereby they still reproduce independently of human intervention (Gepts, 2014). In traditional systems, farming practices still shape the genetic structure of crops and their evolution (Vigouroux *et al.*, 2011).

Downscaling
Downscaling is a method that derives local- to regional scale information from larger-scale models or data analyses (IPCC, 2014b). It is the opposite of upscaling.

Drivers of change
Drivers of change refer to all those external factors that affect nature, and, as a consequence, also affect the supply of nature's contributions to people. The IPBES conceptual framework includes drivers of change as two of its main elements: indirect drivers, which are all anthropogenic, and direct drivers, both natural and anthropogenic. See chapter 1 and chapter 2 (Drivers) for a detailed typology of drivers.

Drivers (direct)
Drivers, both non human-induced and anthropogenic, that affect nature directly. Direct anthropogenic drivers are those that flow from human institutions and governance systems and other indirect drivers. They include positive and negative effects, such as habitat conversion, human-caused climate change, or species introductions. Direct non human-induced drivers can directly affect anthropogenic assets and quality of life (e.g., a volcanic eruption can destroy roads and cause human deaths), but these impacts are not the main focus of IPBES. See chapter 1 and chapter 2.1 (Drivers) for a detailed typology of drivers.

Drivers (indirect)
Human actions and decisions that affect nature diffusely by altering and influencing direct drivers as well as other indirect drivers. They do not physically impact nature or its contributions to people. Indirect drivers include economic, demographic, governance, technological and cultural ones, among others. See chapter 1 and chapter 2 (Drivers) for a detailed typology of drivers.

E

Earth Jurisprudence
An emerging field of law that seeks to develop a philosophy and practice of law that gives greater consideration to nature, by recognizing the interconnectedness of Earth's natural systems, the inherent rights and value of nature, and the dependence of humanity and all living beings on a healthy Earth (United Nations, 2015).

Ecological connectivity
See 'Habitat connectivity'

Ecological disturbance (natural and anthropogenic)
An event that can disrupt any ecological level, environmental component as well as the organizational status of a biological cycle of organisms. Disturbances are an important aspect in the natural selection and the whole biological evolution, as they modify the environment in which every living being performs its vital functions (Battisti *et al.*, 2016).

Ecological footprint
A measure of the amount of biologically productive land and water required to support the demands of an individual, a population or productive activity. Ecological footprints can be calculated at any scale: for an activity, a person, a community, a city, a region, a nation or humanity as a whole.

Ecoregion
A large area of land or water that contains a geographically distinct assemblage of natural communities that:
(a) Share a large majority of their species and ecological dynamics;
(b) Share similar environmental conditions, and;
(c) Interact ecologically in ways that are critical for their long-term persistence (Olson *et al.*, 2004). In contrast to biomes, an ecoregion is generally geographically specific, is at a much finer scale, and contains ecologically interacting biota. For example, the "East African Montane Forest" eco-region of Kenya (WWF ecoregion classification, Olson and Dinerstein, 2002) is a geographically specific and coherent example of the globally occurring "tropical and subtropical forest" biome.

Ecosystem
A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit (Convention on Biological Diversity, 1992).

Ecosystem approach
See 'Ecosystem-based approach'.

Ecosystem ecology
The integrated study of biotic and abiotic components of ecosystems and their interactions within an ecosystem framework. This science examines physical and biological structures and examines how these ecosystem characteristics interact with each other (Simon *et al.*, 2010).

Ecosystem engineer
Organism that changes the abiotic environment by physically altering structure, which often have effects on other biota and their interactions, and on ecosystem processes (Gutiérrez & Jones, 2008).

Ecosystem function
The flow of energy and materials through the biotic and abiotic components of an ecosystem. It includes many processes such as biomass production, trophic transfer through plants and animals, nutrient cycling, water dynamics and heat transfer.

Ecosystem integrity
The ability of an ecosystem to support and maintain ecological processes and a diverse community of organisms. It is measured as the degree to which a diverse community of native organisms is maintained, and is used as a proxy for ecological resilience, intended as the capacity of an ecosystem to adapt in the face of stressors, while maintaining the functions of interest (Ocean Health Index, 2018).

Ecosystem sensitivity
The degree to which an ecosystem is affected, either adversely or beneficially,

by climate related stimuli, including mean (average) climate characteristics, climate variability and the frequency and magnitude of extremes (IUCN, 2012a).

Ecosystem services
The benefits people obtain from ecosystems. According to the original formulation of the Millennium Ecosystem Assessment, ecosystem services were divided into supporting, regulating, provisioning and cultural. See chapter 1 for the equivalence of the concept to the concept of nature's contribution to people predominantly used in this assessment

Ecosystem structure
The individuals and communities of plants and animals of which an ecosystem is composed, their age and spatial distribution, and the non-living natural resources present (IUCN, 2012a).

Ecosystem-based adaptation
The conservation, sustainable management and restoration of natural ecosystems to help people adapt to climate change (Colls *et al.*, 2009).

Ecosystem-based approach
A strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. An ecosystem approach is based on the application of appropriate scientific methods, focused on levels of biological organization that encompass the essential structure, processes, functions and interactions among and between organisms and their environment. It recognizes that humans, with their cultural diversity, are an integral component of many ecosystems (UNEP, 2012).

Ectotherms
Often referred to as cold-blooded and applied to organisms that cannot regulate their body temperature relative to the surrounding environment, i.e., deriving heat from outside the body (FAO, 2018a).

Edge effects
A change in species composition, physical conditions or ecological factors at the boundary between two or more habitats (IUCN, 2012a).

El Niño / La Niña
The term El Niño was initially used to describe a warm-water current that periodically flows along the coast of Ecuador and Perú, disrupting the local fishery. It has since become identified with a basin-wide warming of the tropical Pacific Ocean east of the dateline. This oceanic event is associated with a fluctuation of a global-scale tropical and subtropical surface pressure pattern called the Southern Oscillation. This coupled atmosphere-ocean phenomenon, with preferred time scales of two to about seven years, is collectively known as the El Niño-Southern Oscillation (ENSO) (IPCC, 2014a).

Empowerment
The process by which people gain control over the factors and decisions that shape their lives. It is the process by which they increase their assets and attributes and build capacities to gain access, partners, networks and/or a voice, in order to gain control (WHO, 2010).

Endangered species
A species at risk of extinction in the wild.

Endemic species
Species that is native to, and restricted to, a particular geographical region. Highly endemic species, those with very restricted natural ranges, are especially vulnerable to extinction if their natural habitat is eliminated or significantly disturbed (IUCN, 2012a).

Energy source
Primary energy sources take many forms, including nuclear energy, fossil energy -like oil, coal and natural gas, biomass- and renewable sources like wind, solar, geothermal and hydropower. These primary sources are converted to electricity, a secondary energy source (US Department of Energy, 2018).

Environmental education
The facilitation of an integrated perception of the problems of the environment, enabling more rational actions capable of meeting social needs to be taken (UNESCO, 1978).

Environmental envelope
The environmental envelope of a species is defined as the set of environments within which it is believed that the species can persist: that is where its environmental requirements can be satisfied (see niche). Many large-scale vegetation or species models are based on environmental envelope techniques (Walker & Cocks, 1991).

Environmental gradients
Environmental characteristics that explain the distribution of organisms and ecosystems in terms of environmental tolerances (Government of New Brunswick, 2007).

Environmental Impact Assessment
A formal, evidence-based procedure that assesses the economic, social, and environmental effects of public policy, such as the construction of large-scale infrastructure, or of any human activity.

Environmental justice
The fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation and enforcement of environmental laws, regulations and policies (US Environmental Protection Agency, 2018a).

Environmental Kuznets Curve (EKC)
The hypothesis of an inverted U-shaped relationship between economic output per capita and some measures of environmental quality: as GDP per capita rises, so does environmental degradation. However, beyond a certain point, increases in GDP per capita lead to reductions in environmental damage (Everett *et al.*, 2010).

Environmental taxes / green taxes
A tax whose tax base is a physical unit (or a proxy of it) that has a proven specific negative impact on the environment. Four subsets of environmental taxes are distinguished: energy taxes, transport taxes, pollution taxes and resources taxes (OECD, 2005a).

Epifauna
Animals living on or just above the seabed (IUCN, 2012a).

Epistemic community
A professional network with recognized expertise and competence, and a claim for policy-relevant knowledge, in a particular domain (Haas, 1992).

Essential Biodiversity Variables (EBV)
Essential Biodiversity Variables are promoted by the Group on Earth Observations Biodiversity Observation Network (GEO BON). The idea behind this concept is to identify, using a systems approach, the key variables that should be monitored in order to measure biodiversity change. The Essential Biodiversity Variables are an intermediate layer of abstraction between raw data, from *in situ* and remote sensing observations, and derived high-level indicators used to communicate the state and trends of biodiversity.

Ethnobiology
The study of dynamic relationships among peoples, biota, and environments, as encoded in the knowledge held by different societies and individuals. Its multidisciplinary nature allows it to examine complex, dynamic interactions between human and natural systems, and enhances our intellectual merit and broader impacts (Society of Ethnobiology, 2018).

Eutrophic/eutrophicated habitats
A condition of an aquatic system in which increased nutrient loading leads to progressively increasing amounts of algal growth and biomass accumulation. When the algae die off and decompose, the amount of dissolved oxygen in the water becomes reduced.

Eutrophication
An enrichment of water by nutrients that causes structural changes to the ecosystem, such as: increased production of algae and aquatic plants, depletion of fish species, general deterioration of water quality and other effects that reduce and preclude use (OECD, 1982).

Evapotranspiration
The sum of water loss from both plants and soil measured over a specific area (IUCN, 2012a).

Evenness (biodiversity)
In ecology, species evenness refers to the similarity of abundances of each species in an environment. It can be quantified by a diversity index as a dimension of biodiversity.

Evolutionary anthropology
The interdisciplinary study of the evolution of human physiology and human behaviour and the relation between hominids and non-hominid primates. Evolutionary anthropology is based in the natural and social sciences (McGee, 2003).

Evolutionary biology
A subdiscipline of the biological sciences concerned with the origin of life and the diversification and adaptation of life forms over time (Nature, 2018c).

Exclusive economic zones (EEZs)
An Exclusive Economic Zone (EEZ) is a concept adopted at the Third United Nations Conference on the Law of the Sea (1982), whereby a coastal State assumes jurisdiction over the exploration and exploitation of marine resources in its adjacent section of the continental shelf, taken to be a band extending 200 miles from the shore. The Exclusive Economic Zone (EEZ) comprises an area which extends either from the coast, or in federal systems from the seaward boundaries of the constituent states (3 to 12 nautical miles, in most cases) to 200 nautical miles (370 kilometres) off the coast. Within this area, nations claim and exercise sovereign rights and exclusive fishery management authority over all fish and all Continental Shelf fishery resources (United Nations, 1997).

Extinction
A population, species or more inclusive taxonomic group has gone extinct when all its individuals have died. A species may go extinct locally (population extinction), regionally (e.g., extinction of all populations in a country, continent or ocean) or globally. Populations or species reduced to such low numbers that they are no longer of economic or functional importance may be said to have gone economically or functionally extinct, respectively. Species extinctions are typically not documented immediately: for example, the IUCN Red List categories and criteria require there to be no reasonable doubt that all individuals have died, before a species is formally listed as Extinct (see IUCN Red List, 2012b).

Extinction debt
Local, regional or global extinctions that have not yet taken place, but which have been set in train by environmental impacts - such as habitat destruction, degradation and fragmentation - that have already taken place and that have reduced the site, region or world's carrying capacity for species. Species or populations that make up the extinction debt can be said to be "committed to extinction". The length of time taken to repay the extinction debt is known as the relaxation time, and depends on multiple factors (Kuussaari *et al.*, 2009).

F

Fallow
Land normally used for production and left to recover for part or all of a growing season or in cycles that can vary from few years to decades, such as in the case of swidden agriculture (Gleave, 1996; United Nations, 1997).

Family forestry
Family forestry is forest tenure and activities by persons with ownership or tenure rights to forest land. Persons owning or managing forests often include the extended family in the activities and the forest land goes from one generation to the next (International Family Forestry Alliance, 2016).

Fishery
A unit determined by an authority or other entity that is engaged in raising and/or harvesting fish. Typically, the unit is defined in terms of some or all of the following: people involved, species or type of fish, area of water or seabed, method of fishing, class of boats and purpose of the activities (FAO, 2001a).

Fitness (ecology)
Fitness involves the ability of organisms— or populations or species— to survive and reproduce in the environment in which they find themselves, and thus contribute genes to the next generation (Orr, 2009).

Folk biology
People's everyday understanding of the biological world—how they perceive, categorize, and reason about living kinds (Medin & Atran, 1999).

Folk categories
The units of meaning into which a language breaks up the universe for example, folk plant and animal taxa (Berlin, 1973).

Food security
The World Food Summit of 1996 defined food security as existing "when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life".

Food web / food web interactions
An important ecological concept representing feeding relationships within a community and implying the transfer of food energy from its source in plants through herbivores to carnivores; normally, food webs consist of a number of food chains meshed together (Hui, 2012).

Forest
A vegetation type dominated by trees. Definitions of forest varies according to the use of parameters such as biogeography, physiognomy, biomass, human management, species dominance and composition, among others, therefore affecting estimates of extent and type of change (also see IPCC, 2014a).

Forest degradation
A process leading to a temporary or permanent deterioration in the density or

structure of vegetation cover or its species composition. It is a change in forest attributes that leads to a lower productive capacity caused by an increase in disturbances. Continued degradation of the forests can destroy the entire forest cover and biodiversity, and it mainly occurs because of environmental and anthropogenic changes (Tejawasi, 2007).

Forest garden
A range of systems for the management of forest resources that are intermediate on a continuum between pure extraction and plantation management, and ranging from wild forests modified for increased production of selected products (e.g., fruit and nut trees) to anthropogenic forests with a high density of valuable species within a relatively diverse and complex structure (Belcher *et al.*, 2005).

Forest Law Enforcement, Governance and Trade (FLEGT)
A reduction of illegal logging by strengthening sustainable and legal forest management, improving governance and promoting trade in legally produced timber (EUFLEGT Facility, 2018a).

Forest transition
Attributed to Mather (1992), this term denotes a process of land-use change in a country or region with a period of decline in forest cover, during earlier economic development, then forest recovery.

Fossil fuels
Fossil fuels are derived from the remains of ancient plant and animal life: coal, oil and natural gas. In common dialogue, the term fossil fuel also includes hydrocarbon-containing natural resources that are not derived from animal or plant sources (OECD, 2001a).

Free, prior and informed consent (FPIC) / prior, informed consent
Free implies that Indigenous Peoples and Local Communities are not pressured, intimidated, manipulated or unduly influenced and that their consent is given, without coercion; prior implies seeking consent or approval sufficiently in advance of any authorization to access traditional knowledge respecting the customary decision-making processes in accordance with national legislation and time requirements of Indigenous Peoples and Local Communities; informed implies that information is provided that covers relevant aspects, such as: the intended purpose of the access; its duration and scope; a preliminary assessment of the likely economic, social, cultural and environmental impacts, including potential risks; personnel likely to be involved in the execution of the access; procedures the access may entail and benefit-sharing arrangements; consent or approval is the agreement of the Indigenous Peoples and Local Communities who are holders of traditional knowledge or the competent authorities of those Indigenous Peoples and Local Communities, as appropriate, to grant access to their traditional knowledge to a potential user and includes the right not to grant consent or approval (derived from CBD, 2018b).

Functional diversity
The range, values, relative abundance and distribution of functional traits in a given community or ecosystem (Diaz *et al.*, 2007).

Functional extinction
See 'Exctinction'.

Functional group
A collection of organisms with similar suites of co-occurring functional attributes. Groups are traditionally associated with similar responses to external factors and/or effects on ecosystem processes. A functional group is often referred to as 'guild', especially when referring to animals, e.g., the feeding types of aquatic organisms having the same function within the trophic chain (De Bello *et al.*, 2010).

Functional redundancy
The occurrence in the same ecosystem of species filling similar roles, which results in a sort of "insurance" in the ecosystem, with one species able to "replace" a similar species from the same functional niche (Rosenfeld, 2002).

Functional traits
Any feature of an organism, expressed in the phenotype and measurable at the individual level, which has demonstrable links to the organism's function (Lavorel *et al.*, 1997; Violle *et al.*, 2007). As such, a functional trait determines the organism's response to external abiotic or biotic factors (Response trait), and/or its effects on ecosystem properties or benefits or detriments derived from such properties (Effect trait). In plants, functional traits include morphological, ecophysiological, biochemical and regeneration traits. In animals, these traits include e.g., body size, litter size, age of sexual maturity, nesting habitat, time of activity.

G

Gene
The basic physical and functional unit of heredity. Genes are made up of DNA, and occupy a fixed position (locus) on a chromosome. Genes achieve their effects by directing the synthesis of proteins (Encyclopaedia Britannica, 2018).

Gene flow
The movement of individuals, and/or the genetic material they carry, from one population to another. Gene flow includes lots of different kinds of events, such as pollen being blown to a new destination or people moving to new cities or countries (University of California Museum of Paleontology, 2018a).

Generalist species
A species able to thrive in a wide variety of environmental conditions and that can make use of a variety of different resources (for example, a flower-visiting insect that lives on the floral resources provided by several to many different plants).

Genetic composition
The composition in alleles of a population (University of Leicester, 2018).

Genetic diversity
The variation at the level of individual genes, which provides a mechanism for populations to adapt to their ever-changing environment. The more variation, the better the chance that at least some of the individuals will have an allelic variant that is suited for the new environment, and will produce offspring with the variant that will in turn reproduce and continue the population into subsequent generations (NBII, 2011).

Genetic engineering
The artificial manipulation, modification, and recombination of DNA or other nucleic acid molecules in order to modify an organism or population of organisms.

Genetic erosion
The loss of genetic diversity, including the loss of individual genes or particular combinations of genes, and loss of varieties and crops (Vetriventhan *et al.*, 2016).

Genetic resources
Genetic material of actual or potential value (Convention on Biological Diversity, 1992).

Genetically Modified Organism (GMO)
Organism in which the genetic material (DNA) has been altered in a way that does not occur naturally by mating and/or natural recombination (WHO, 2014). The Cartagena Protocol on Biosafety defines ‘living modified organism’ as any living organism that possesses a novel combination of genetic material obtained through the use of modern biotechnology (CBD, 2000).

Genotype
The genetic constitution of an individual or group (IUCN, 2012a).

Germplasm
Living tissue from which new plants can be grown. It can be a seed or another plant part – a leaf, a piece of stem, pollen or even just a few cells that can be turned into a whole plant (University of California Seed Biotechnology Center, 2018).

Gini index
The Gini index measures the extent to which the distribution of income (or, in some cases, consumption expenditure or other variables) among individuals or households within an economy deviates from a perfectly equal distribution. A Gini index of 0 represents perfect equality, while an index of 100 implies perfect inequality (World Bank, 2018).

Global commons or global common pool resources (CPR)
Common pool resources (CPR) that have a global nature, such as the atmosphere, the oceans, global species diversity, migratory species, global biogeochemical processes, among others. It does not refer to property rights, such as a common property system. In general, CPR include natural and human-constructed resources in which (i) exploitation by one user reduces resource availability for others, and (ii) exclusion of beneficiaries through physical and institutional means is especially costly. These two characteristics – difficulty of exclusion and subtractability – create potential CPR dilemmas in which people following their own short-term interests produce outcomes that are not in anyone’s long-term interest (Ostrom *et al.*, 1994).

Global North – Global South
The Global South and the Global North is a terminology that distinguishes not only between political systems or degrees of poverty, but between the victims and the benefactors of global capitalism (Wolvers *et al.*, 2015).

Good Quality of Life (GQL)
Within the context of the IPBES Conceptual Framework – the achievement of a fulfilled human life, a notion which may varies strongly across different societies and groups within societies. It is a context-dependent state of individuals and human groups, comprising aspects such as access to food, water, energy and livelihood security, and also health, good social relationships and equity, security, cultural identity, and freedom of choice and action. “Human wellbeing”, “inclusive wealth”, “living in harmony with nature”, “living-well in balance and harmony with Mother Earth” are examples of different perspectives on a “Good quality of life”. See detailed description in chapter 1.

Governance
A comprehensive and inclusive concept of the full range of means for deciding, managing, implementing and monitoring actions and measures, including policies. Whereas government is defined strictly in terms of the nation-state, the more inclusive concept of governance recognizes the contributions of various levels of government (global, international, regional, sub-national and local) and the contributing roles of the private sector, of nongovernmental actors, and of civil society to addressing the many types of issues from local to global levels (adapted from IPCC, 2018).

Great Acceleration
Great Acceleration refers to the acceleration of human-induced changes of the second half of the 20th century, unique in scale in the history of human existence. Many human activities reached take-off points and sharply accelerated since the 1950s with world regions changing their contributions to globally-aggregated changes over time (adapted from International Geosphere-Biosphere Programme, 2015).

Green bonds
A mode of private financing that tap the debt capital market through fixed income instruments (i.e., bonds) to raise capital to finance climate-friendly projects in key sectors of, but not limited to, transport, energy, building and industry, water, agriculture and forestry and waste (OECD, 2017).

Green growth
Green growth means fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies (OECD, 2018a).

Green infrastructure / grey infrastructure
Green infrastructure refers to the natural or semi-natural systems (e.g., riparian vegetation) that provide services for water resources management with equivalent or similar benefits to conventional (built) “grey” infrastructure (e.g., water treatment plants) (UNEP, 2014).

Green Revolution
A term attributed to a period of food crop productivity growth that started in the 1960s due to a combination of high rates of investment in crop research, infrastructure, market development, and policy support, and whose environmental impacts have been mixed: on the one side, it is said to have contributed to saving land conversion to agriculture, on the other side, it is said to have contributed to promoting an overuse of inputs and cultivation on areas otherwise improper to high levels of intensification, such as slopes, and high levels of pesticide pollution (adapted from Pingali, 2012). It is also argued that development policies promoting the Green Revolution contributed to undermine otherwise productive and resilient locally-based food production systems.

Greenhouse gases (GHGs)
Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth’s surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth’s atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine- and brominecontaining substances, dealt with under the Montreal Protocol. Beside CO_2, N_2O and CH_4, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride (SF6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) (IPCC, 2014a).

Gross primary productivity
The amount of carbon fixed by the autotrophs (e.g., plants and algaes) (IPCC, 2014a).

Habitat
The place or type of site where an organism or population naturally occurs. Also used to mean the environmental attributes required by a particular species or its ecological niche.

Habitat connectivity
The degree to which the landscape or waterscape facilitate the movement of organisms (animals, plant reproductive structures, pollen, pollinators, spores, etc.) and other environmentally important resources (e.g., nutrients and moisture) between similar habitats. Connectivity is hampered by fragmentation (q.v.).

Habitat degradation
A general term describing the set of processes by which habitat quality is reduced. Habitat degradation may occur through natural processes (e.g., drought, heat, cold) and through human activities (forestry, agriculture, urbanization). It is sometimes used as a synonym of habitat deterioration or nature deterioration.

Habitat fragmentation
A general term describing the set of processes by which habitat loss results in the division of continuous habitats into a greater number of smaller patches of lesser total and isolated from each other by a matrix of dissimilar habitats. Habitat fragmentation may occur through natural processes (e.g., forest and grassland fires, flooding) and through human activities (forestry, agriculture, urbanization).

Habitat heterogeneity
The number of different habitats in a landscape (Cramer & Willig, 2005).

Habitat modification
Changes in an area's primary ecological functions and species composition due to human activity and/or non-native species invasion (UNEP-WCMC, 2014).

Habitat specialist
Species that require very specific habitats and resources (e.g., narrow range of food sources or cover types) to thrive and reproduce (Maryland State Wildlife Action Plan, 2015).

Harmful algal blooms (HABs)
Harmful algal blooms (HABs) occur when colonies of algae grow out of control and produce toxic or harmful effects on people, fish, shellfish, marine mammals and birds. The human illnesses caused by HABs, though rare, can be debilitating or even fatal (NOAA, 2016).

Heat island effect
Describes built up areas that are hotter than nearby rural areas. Heat islands can affect communities by increasing summertime peak energy demand, air conditioning costs, air pollution and greenhouse gas emissions, heat-related illness and mortality, and water quality (US Environmental Protection Agency, 2018b).

Holocene
The Holocene is the current geological epoch. It began after the Pleistocene, approximately 11,650 calendar years before present.

Homegarden
Areas surrounding a house for vegetable and fruit production and keeping of domestic animals. In many regions homegardens contain wild species utilized as medicinal plants, timber or other uses (Walker *et al.*, 2009).

Homeotherms
Organisms (vertebrates) with a constant and high body temperature, with a high level of energy exchange (Ivanov, 2006).

Hotspot of agrobiodiversity
Areas with significantly high levels of agrobiodiversity.

Hotspot of endemism
See 'Biodiversity hotspot'

Human appropriation of net primary production (HANPP)
The aggregate impact of land use on biomass available each year in ecosystems (Haberl *et al.*, 2007).

Human capital
Human capital is the stock of skills that people possess. It encompasses the notion that there are investments in people (e.g., education, training, health) and that these investments increase an individual's productivity (Goldin, 2016). In the IPBES conceptual framework, human capital is part of anthropogenic assets.

Human history
A general term used to refer to pre-historical and historical periods describing the development of humanity. Different classifications of periods exist reflecting different interpretation of human history.

Human-induced climate change
Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1 of the UNFCCC, "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes (IPCC, 2014a) (please see related definition for climate change above).

Hunting
The capture by humans of wild mammals, birds, and reptiles, whether dead or alive, irrespective of the techniques used to capture them or the reasons to do so (Bennett & Robinson, 2000).

Hypoxia
Low dissolved oxygen levels in coastal and oceanic waters (<2mL per liter of water), either naturally occurring or as a result of a degradation (e.g., eutrophication) (Altieri *et al.*, 2017; Diaz & Rosenberg, 2008).

I

Identity
The ways in which people understand who they are, their belonging and role in society, and their relation to their broader environment (Fearon, 1999; Ingalls & Stedman, 2017). Identity can be multiple and situational.

Illegal logging
The harvesting, processing, transporting, buying or selling of timber in contravention of national and international laws (EUFLEGT Facility, 2018b).

Illegal, unreported and unregulated (IUU) fishing
A broad term which includes: fishing and fishing-related activities conducted in contravention of national, regional and international laws; non-reporting, misreporting or under- reporting of information on fishing operations and their catches; fishing by "Stateless" vessels; fishing in convention areas of Regional Fisheries Management Organizations (RFMOs) by non-party vessels; fishing activities which are not regulated by States and cannot be easily monitored and accounted for (FAO, 2016).

***In situ* conservation of biodiversity and agrobiodiversity**
The conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties (Convention on Biological Diversity, 1992)

Indicator
A quantitative or qualitative factor or variable that provides a simple, measurable and quantifiable characteristic or attribute responding in a known and communicable way to a changing environmental condition, to a changing ecological process or function, or to a changing element of biodiversity.

Indigenous and local knowledge (ILK)
The knowledge, practices and innovations embedded in the relationships of Indigenous Peoples and Local Communities to nature. ILK is situated in a place and social context, but at the same time open and hybrid, continuously evolving through the combination of written, oral, tacit, practical, and scientific knowledge attained from various sources, and validated by experimentation and in practice of direct interaction with nature. See chapter 1 (section 1.3.2.1) and chapter 2.2 (section 2.2.2) for a discussion on the differences between 'indigenous knowledge' and 'local knowledge'.

Indigenous and local knowledge (ILK) systems
Indigenous and local knowledge systems are social and ecological knowledge practices and beliefs pertaining to the relationship of living beings, including people, with one another and with their environments. Such knowledge can provide information, methods, theory and practice for sustainable ecosystem management.

Indigenous Peoples and Local Communities (IPLCs)
The Convention on Biological Diversity does not define the terms indigenous and local communities or Indigenous Peoples and Local Communities. The United Nations Declaration on the Rights of Indigenous Peoples does not adopt or recommend a universal definition for Indigenous Peoples (Decision CBD/COP/DEC/14/13). As used in the global assessment, Indigenous Peoples and Local Communities (IPLCs) is a term used internationally by representatives, organizations, and conventions to refer to individuals and communities who are, on the one hand, self-identified as indigenous and, on the other hand, are members of local communities that maintain inter-generational connection to place and nature through livelihood, cultural identity and worldviews, institutions and ecological knowledge. The term is not intended to ignore differences and diversity within and among Indigenous Peoples and between them and local communities; Indigenous Peoples have recognized and distinct rights, which are not extendable to the broader and encompassing concept of local communities. See chapter 1 (Section 1.3.2.1).

Indigenous Peoples' and community conserved territories and areas (ICCAs)
Natural and/or modified ecosystems containing significant biodiversity values, ecological services and cultural values, voluntarily conserved by Indigenous Peoples and Local Communities, both sedentary and mobile, through customary laws or other effective means (CBD, 2018b).

Individual fishing quotas (IFQs)
An allocation to an individual (a person or a legal entity (e.g., a company)) of a right [privilege] to harvest a certain amount of fish in a certain period of time. It is also often expressed as an individual share of an aggregate quota, or total allowable catch (TAC) (OECD, 2001b).

Individual transferable quotas (ITQs)
A type of quota (a part of a Total Allowable Catch) allocated to individual fishermen or vessel owners and which can be sold to others (OECD, 2005b).

Infauna
Animals that live within the sediment (IUCN, 2012a).

Institutions
Institutions encompass formal and informal rules and norms that structure individual and collective behaviour, including interactions among stakeholders and social structures that help to define how decisions are taken and implemented, how power is exercised, and how responsibilities are distributed.

Insular systems
Any area of habitat suitable for a specific ecosystem, surrounded by an expanse of unfavorable habitat that limits the dispersal of individuals. Insular systems can be either physical islands or isolated habitats (e.g., resulting of fragmentation) (Brown, 1978).

Integrated Assessment Models (IAMs)
Interdisciplinary models that aim to describe the complex relationships between environmental, social, and economic drivers that determine current and future state of the ecosystem and the effects of global change, in order to derive policy-relevant insights. One of the essential characteristics of integrated assessments is the simultaneous consideration of the multiple dimensions of environmental problems.

Integrated pest management (IPM)
Integrated Pest Management (IPM) is an ecosystem approach to crop production and protection that combines different management strategies and practices to grow healthy crops and minimize the use of pesticides (FAO, 2018b).

Integrated Water Resource Management (IWRM)
A process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (Hassing *et al.*, 2009).

Intellectual property rights
Intellectual property rights are the rights given to persons over the creations of their minds. They usually give the creator an exclusive right over the use of his/her creation for a certain period of time. Intellectual property rights are customarily divided into two main areas: rights related to copyright and industrial property (World Trade Organization, 2018).

Intercropping
Refers to growing two or more crops in the same field at the same time (FAO, 2018a).

Intermediate disturbance hypothesis
The intermediate disturbance hypothesis (IDH) suggests that local species diversity is maximized when ecological disturbance is neither too rare nor too frequent (Connell, 1978).

Invasive alien species (IAS)
Species whose introduction and/or spread by human action outside their natural distribution threatens biological diversity, food security, and human health and well-being. "Alien" refers to the species'

having been introduced outside its natural distribution ("exotic", "non-native" and "non-indigenous" are synonyms for "alien"). "Invasive" means "tending to expand into and modify ecosystems to which it has been introduced". Thus, a species may be alien without being invasive, or, in the case of a species native to a region, it may increase and become invasive, without actually being an alien species.

IPBES conceptual framework
A simplified representation of the complex interactions between the natural world and human societies. This framework emerged from an extensive process of consultation and negotiation, leading to formal adoption by the second IPBES Plenary (IPBES/2/4), and therefore represents a key foundation for all IPBES activities. The framework recognizes different knowledge systems, including indigenous and local knowledge (ILK) systems, which can be complementary to those based on science (see chapter 1 for detailed description).

IUCN Red List
The IUCN Red List is an indicator of the health of biodiversity. It provides taxonomic, conservation status and distribution information on plants, fungi and animals that have been globally evaluated using the IUCN Red List Categories and Criteria. This system is designed to determine the relative risk of extinction, and the main purpose of the IUCN Red List is to catalogue and highlight those plants and animals that are facing a higher risk of global extinction (IUCN, 2012b).

J

Jevons paradox
See 'Rebound effect'.

Joint production
See 'Co-production'.

K

Key Biodiversity Areas (KBAs)
Sites contributing significantly to the global persistence of biodiversity. They represent the most important sites for biodiversity conservation worldwide, and are identified nationally using globally standardized criteria and thresholds (UNEP-WCMC, 2014).

Keystone species
A species whose impact on the community or ecosystem is disproportionately large relative to its abundance. Effects can be produced by consumption (trophic interactions), competition, mutualism, dispersal, pollination, disease, or habitat modification (nontrophic interactions) (Millenium Ecosystem Assessment, 2005).

L

Land cover
The physical coverage of land, usually expressed in terms of vegetation cover or lack of it. Related to, but not synonymous with, land use (Millenium Ecosystem Assessment, 2005).

Land degradation
Refers to the many processes that drive the decline or loss in biodiversity, ecosystem functions or their benefits to people and includes the degradation of all terrestrial ecosystems. See 'Habitat degradation'.

Land grabbing
See 'Large-scale land acquisition'.

Land sharing and sparing
Concepts used to describe, in general terms, spatial-temporal arrangements of agricultural and non-agricultural areas. Land sharing is a situation where farming practices enable biodiversity to be maintained within agricultural landscapes. Land sparing, also called "land separation" involves restoring or creating non-farmland habitat in agricultural landscapes at the expense of field-level agricultural production - for example, woodland, natural grassland, wetland, and meadow on arable land. This approach does not necessarily imply high-yield farming of the non-restored, remaining agricultural land (Rey Benayas & Bullock, 2012). See also 'Conservation agriculture'.

Land use
The human use of a piece of land for a certain purpose (such as irrigated agriculture or recreation or conservation). Influenced by, but not synonymous with, land cover (Millenium Ecosystem Assessment, 2005). Land-use change refers to a change in the use or management of land by humans, which may lead to a change in land cover.

Land use intensification
Activities undertaken with the intention of enhancing the productivity or profitability per unit area of land use, such as in agriculture, including intensification of particular land uses as well as changes between land uses (Martin *et al.*, 2018).

Landrace
A breed that has largely developed through adaptation to the natural environment and traditional production system in which it has been raised (FAO, 2013).

Landscape
An area of land that contains a mosaic of ecosystems, including human-dominated ecosystems.

Landscape functioning
The capacity or potential of landscapes to maintain ecosystem functions and to provide services (adapted from Bolliger & Kienast, 2010).

Landscape heterogeneity
Landscape heterogeneity is a complex phenomenon involving the size, shape and composition of different landscape units and the spatial (and temporal) relations between them, such as between different land cover types (Cale & Hobbs, 1994).

Large-scale land acquisition (LSLA)
The control (whether through ownership, lease, concession, contracts, quotas, or general power) of larger than locally-typical amounts of land by any persons or entities (public or private, foreign or domestic) via any means ('legal' or 'illegal') for purposes of speculation, extraction, resource control or commodification usually at the expense of local ownership and access, agroecological principles, customary forms of land stewardship, and affecting food sovereignty and human rights (adapted from Baker-Smith & Miklos-Attila, 2016). It is sometimes also called "land grabbing".

Law of the Sea
The United Nations Convention on the Law of the Sea (UNCLOS), in force since 1994, defines the rights and obligations of nations (167 at present) with regard to the use of the world's oceans and their resources, and the protection of the marine and coastal environment. The UNCLOS also defines national marine jurisdiction on maritime territories and provides guidelines related to the use and management of marine environment and resources.

Leaf Area Index (LAI)
The total area of green leaves per unit area of ground covered (FAO, 2018a).

Leakage effect
Phenomena whereby the reduction in emissions (relative to a baseline) in a

jurisdiction/sector associated with the implementation of mitigation policy is offset to some degree by an increase outside the jurisdiction/sector through induced changes in consumption, production, prices, land use and/or trade across the jurisdictions/sectors. Leakage can occur at a number of levels, be it a project, state, province, nation or world region (IPCC, 2014a).

Learning (traditional and formal)
Learning refers to the process of knowledge and skills acquisition. Studies on learning have payed attention to the different ways people acquire knowledge, practices, and beliefs (i.e., imitation, copying, trial-and-error), but also to the dynamics of knowledge transmission, or the different sources from which knowledge, practices, and beliefs are passed from one individual to another (i.e., from parents, peers, teachers, prestigious peoples, media, etc). Social learning is defined as the acquisition of new information by observing and emulating others, and it is a key human strategy that allows for the accumulation of culturally transmitted knowledge (Boyd & Richerson, 2005; Boyd & Silk, 2014).

M

Macroecology
A subfield of ecology that deals with the study of relationships between organisms and their environment at large spatial scales, and involves characterizing and explaining statistical patterns of abundance, distribution and diversity (Blackburn & Gaston, 2002).

Maladaptation
A trait that is, or has become, more harmful than helpful, in contrast with an adaptation, which is more helpful than harmful (Barnett & O'Neill, 2010).

Malnutrition
Malnutrition refers to deficiencies, excesses or imbalances in a person's intake of energy and/or nutrients. The term malnutrition covers 2 broad groups of conditions. One is 'undernutrition'—which includes stunting (low height for age), wasting (low weight for height), underweight (low weight for age) and micronutrient deficiencies or insufficiencies (a lack of important vitamins and minerals). The other is overweight, obesity and diet-related noncommunicable diseases (such as heart disease, stroke, diabetes and cancer) (WHO, 2016).

Marginal lands
Land having limitations which in aggregate are severe for sustained application of a given use. On these lands, options are limited for diversification without the use of inputs; inappropriate management of lands may cause irreversible degradation (CGIAR, 1999).

Marginalization
Marginalization refers to the set of processes through which some individuals and groups face systematic disadvantages in their interactions with dominant social, political and economic institutions. The disadvantages arise from class status, social group identity (kinship, ethnicity, caste and race categories), political affiliation, gender, age and disability (Institute of Development and Economic Alternatives, 2016).

Mariculture
A branch of aquaculture involving the culture of organisms in a medium or environment which may be completely marine (sea), or sea water mixed to various degrees with fresh water, including brackishwater areas (Sivalingam, 1981).

Mechanistic modelling
A model with hypothesized relationship between the variables in the dataset where the nature of the relationship is specified in terms of the biological processes that are thought to have given rise to the data.

Megadiverse country
Countries (17) which have been identified as the most biodiversity-rich countries of the world, with a particular focus on endemic biodiversity (UNEP-WCMC, 2014).

Mesic areas
Synonym for moist areas (IUCN, 2012a).

Meta-analysis
A quantitative statistical analysis of several separate but similar experiments or studies in order to test the pooled data for statistical significance.

Metabolic activity
Chemical transformations that sustain life at the cell level.

Microevolution
A change in gene frequency within a population. Evolution at this scale can be observed over short periods of time — for example, between one generation and the next, the frequency of a gene for pesticide resistance in a population of crop pests increases. Such a change might come about because natural selection favored the gene, because the population received new immigrants carrying the gene, because some nonresistant genes mutated to the resistant version, or because of random genetic drift from one generation to the next (University of California Museum of Paleontology, 2018b).

Micro-habitats
The small-scale physical requirements of a particular organism or population.

Micronutrients
Substances that are only needed in very small amounts but essential to organisms to produce enzymes, hormones and other substances fundamental for proper growth and development (WHO, 2015).

Microparticles
Particles with dimensions between 0.1 and 100 micrometers, e.g., pollen, sand, dust (Vert *et al.*, 2012).

Micro-plastics
Plastic debris that are less than five millimeters in length (NOAA, 2018a).

Minimum tillage
Minimum tillage systems are tillage systems in which the ground is worked very little before the seed is sown, and where crops can be sown almost immediately after the previous crop has been harvested (Rawson & Gómez Macpherson, 2000).

Moisture recycling
The contribution of local evaporation and evapotranspiration to local precipitation (Trenberth & Trenberth, 1999).

Monitoring
The repeated observation of a system in order to detect signs of change in relation to a predetermined or expected standard.

Monoculture
The agricultural practice of cultivating a single crop over a whole farm or area (FAO, 2001b).

Monophyletic
The condition in which a group of taxa share a common ancestry, being the entire set of evolutionary descendants from a common ancestor.

Mother Earth
An expression used in a number of countries and regions to refer to the planet Earth and the entity that sustains all living things found in nature with which humans have an indivisible, interdependent physical and spiritual relationship (see ‘Nature’).

Mutualism
Interaction between two species that benefits the two species (Bronstein, 1994).

N

Nagoya protocol
The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization (ABS) is a supplementary agreement to the 1992 Convention on Biological Diversity. It provides a transparent legal framework for the effective implementation of one of the three objectives of the CBD: the fair and equitable sharing of benefits arising out of the utilization of genetic resources, thereby contributing to the conservation and sustainable use of biodiversity. The Nagoya Protocol aims to create greater legal certainty and transparency for both providers and users of genetic resources by establishing more predictable conditions for access to genetic resources and helping to ensure benefit-sharing when genetic resources leave the country providing the genetic resources. The Nagoya Protocol on ABS was adopted on 29 October 2010 in Nagoya, Japan and entered into force on 12 October 2014.

National biodiversity strategies and action plans (NBSAPs)
The Convention on Biological Diversity calls on each of its Parties to prepare a National Biodiversity Strategy and Action Plan (Article 6a) that establishes specific activities and targets for achieving the objectives of the Convention. These plans mostly are implemented by a partnership of conservation organizations. Species or habitats which are the subject of NBSAPs are the governments stated priorities for action and therefore raise greater concern where they are threatened. NBSAPs do not carry legal status and listed species and habitat types are not necessarily protected (although some are covered by other legislation) (Hesselink *et al.*, 2007).

Natural capital
A concept referring to the stock of renewable and non-renewable natural resources (e.g., plants, animals, air, water, soils, minerals) that combine to yield a flow of benefits to people (UNDP, 2016b). Within the IPBES conceptual framework, it is part of the “nature” category, representing an economic-utilitarian perspective on nature, specifically those aspects of nature that people use (or anticipate to use) as source of NCP (see chapter 1).

Natural habitat
Areas composed of viable assemblages of plant and/or animal species of largely native origin and/or where human activity had not essentially modified an area’s primary ecological functions and species composition (UNEP-WCMC, 2014).

Natural heritage
Natural features, geological and physiographical formations and delineated areas that constitute the habitat of threatened species of animals and plants and natural sites of outstanding universal value from the point of view of science, conservation or natural beauty (UNESCO, 1972).

Nature
In the context of IPBES (also referred as “living nature”), it refers to the nonhuman world, including coproduced features, with particular emphasis on living organisms, their diversity, their interactions among themselves and with their abiotic environment. Within the framing of the natural sciences, nature include e.g., all dimensions of biodiversity, species, genotypes, populations, ecosystems, communities, biomes, Earth life support’s systems, and their associated ecological, evolutionary and biogeochemical processes. Within the framework of economics, it includes categories such as biotic natural resources, natural capital and natural assets. Within a wider context of social sciences and humanities and interdisciplinary environmental sciences, it is referred to with categories such as natural heritage, living environment, or the nonhuman. Within the framing of other knowledge systems, it includes categories such as Mother Earth (shared by many IPLC around the world; see ‘Mother Earth’), Pachamama (South American Andes), se¯nluo´-wa`nxia`ng and tien-ti (East Asia), Country (Australia) , fonua/vanua/whenua/ples (South Pacific Islands), Iwigara (Northern Mexico), Ixofijmogen (Southern Argentina and Chile), among many others. The degree to which humans are considered part of nature varies strongly across these categories. Many aspects of biocultural diversity are part of nature, while some others pertain more to nature’s contributions to people and anthropogenic assets (also see Chapter 1).

Nature-based solutions
Actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (Cohen-Shacham *et al.*, 2016).

Nature’s contributions to people (NCP)
Nature’s contributions to people (NCP) are all the contributions, both positive and negative, of living nature (i.e., all organisms, ecosystems, and their associated ecological and evolutionary processes) to people’s quality of life. Beneficial contributions include e.g., food provision, water purification, flood control, and artistic inspiration, whereas detrimental contributions include e.g., disease transmission and predation that damages people or their assets. NCP may be perceived as benefits or detriments depending on the cultural, temporal or spatial context (Díaz *et al.*, 2018). IPBES considers a gradient of approaches to NCP, ranging from a purely generalizing approach to a purely context-specific one. Within the generalizing approach, IPBES identifies 18 categories of NCP, organized in three partially overlapping groups:

- Material contributions are substances, objects or other material elements from nature that directly sustain people’s physical existence and material assets. They are typically physically consumed in the process of being experienced, for example when organisms are transformed into food, energy, or materials for clothing, shelter or ornamental purposes.
- Non-material contributions are nature’s effects on subjective or psychological aspects underpinning people’s quality of life, both individually and collectively. Examples include forests and coral reefs providing opportunities for recreation and inspiration, or particular organism (animals, plants, fungi) or habitat (mountains, lakes) being the basis of spiritual or social-cohesion experiences.
- Regulating contributions are functional and structural aspects of organisms and ecosystems that modify environmental conditions experienced by people, and/or regulate the generation of material and non-material contributions. Regulating contributions frequently affect quality of

life in indirect ways. For example, people directly enjoy useful or beautiful plants, but only indirectly the soil organisms that are essential for the supply of nutrients to such plants.
(see chapters 1 and 2.3 for detailed definitions)

NCP (potential)
The capacity of an ecosystem to provide NCP (see chapter 2.3).

NCP (realized)
The actual flow of NCP that humanity receives. Realized NCP typically depends not only on potential NCP but also anthropogenic assets (e.g., boats and fishing gear, or farm equipment), human labor, and institutions. Institutions can facilitate or prevent access to resources and are often important for determining whether or not potential NCP generates realized NCP (see chapter 2.3).

Neo-endemic taxa
Recently diverged taxa that are endemic because of lack of dispersal/migration out of their ancestral area, as opposed to paleo-endemic taxa that were perhaps more widespread in the past and are now restricted to a local region (Mishler *et al.*, 2014).

Net Primary Production (NPP)
The difference between how much CO_2 vegetation takes in during photosynthesis (gross primary production) minus how much CO_2 the plants release during respiration (NASA Earth Observatory, 2018). It corresponds to the increase in plant biomass or carbon of a unit of a landscape (IPCC, 2001).

Nexus
A perspective which emphasizes the inter-relatedness and interdependencies of ecosystem components and human uses, and their dynamics and fluxes across spatial scales and between compartments. Instead of just looking at individual components or a specific sector (e.g., water, energy, food), the functioning, productivity and management of a complex system is taken into consideration. In such complex systems there are trade-offs as well as facilitation and amplification between the different components. A nexus approach can help address synergies and trade-offs among multiple sectors and among various Sustainable Development Goals and biodiversity targets simultaneously (adapted from UNU-FLORES, 2018; also see Chapter 5).

Niche (ecological)
A species' position within an ecosystem. This definition includes both the abiotic and biotic conditions necessary for the species to be able to persist (e.g., temperature range, food sources) and its ecological role, function or "job" (Polechová & Storch, 2008).

Niche models
Also known as species distribution models, niche models predict the spatial distribution of a species as a function of environmental variables. They are often used to project the future distributions of species in response to climate change (Wiens *et al.*, 2009).

Nitrogen deposition
The nitrogen transferred from the atmosphere to the Earth's surface by the processes of wet deposition and dry deposition (IPCC, 2014a).

Nitrogen-fixing species
Plants, such as legumes, living in symbiosis with micro-organisms in their roots that can perform biological nitrogen fixation, i.e., convert atmospheric nitrogen (N2) to ammonia (NH3). Plants can then assimilate NH3 to produce biomolecules (Wagner, 2011).

Non-timber forest products (NTFPs)
Any biological resources found in forests other than timber, including fruits, fuel wood and small wood, nuts, seeds, oils, foliage, game animals, berries, medicinal plants, fish, spices, barks, and mushrooms, among others (Prasad, 1993).

NOX
A generic term for the nitrogen oxides most relevant for air pollution (NO and NO2) (Omidvarborna *et al.*, 2015).

Nutrient availability
Nutrients that can be extracted by plant roots, generally from the soil (Silver, 1994).

Nutrient cycling
The processes by which elements are extracted from their mineral, aquatic, or atmospheric sources or recycled from their organic forms, converting them to the ionic form in which biotic uptake occurs and ultimately returning them to the atmosphere, water, or soil (Millenium Ecosystem Assessment, 2005).

O

Ocean acidification
A reduction in the pH of the ocean over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide from the atmosphere, but can also be caused by other chemical additions or subtractions from the ocean. Anthropogenic ocean acidification refers to the component of pH reduction that is caused by human activity (IPCC, 2014a).

Oceanic gyre
Large system of rotating ocean currents. There are five major gyres: the North and South Pacific Subtropical Gyres, the North and South Atlantic Subtropical Gyres, and the Indian Ocean Subtropical Gyre (NOAA, 2018c).

Oceanic oxygen minimum zones (OMZs)
Oxygen-deficient layers in the ocean water column. OMZs correspond to subsurface oceanic zones reaching ultra-low values of O_2 concentration (Paulmier & Ruiz-Pino, 2008).

Old-growth forest
From an ecological point of view, old-growth forests are a stage of forest development characterized by large/old trees and structural complexity including live and dead trees, and vertical and horizontal heterogeneity (including a multi-layered canopy). The structural diversity of old growth forests often supports distinctive/specialist biodiversity; large/old trees are keystone components of the ecosystem (Lindenmayer *et al.*, 2012).
In addition, the long-period of forest development without stand replacement disturbance allows many poor-dispersing species to accumulate (IUFRO, 2018). Other definitions can be found based on economic and social perspectives (Hilbert & Wienscczyk, 2007).

Oligotrophic
Nutrient-poor environment (IUCN, 2012a).

Ontology
The philosophical study of the nature of being, becoming, existence, or reality, as well as the basic categories of beings and their relations.

Open Ocean Pelagic Systems (OOPS)
Marine ecosystems in the light-flooded (euphotic) zone.

Organic agriculture
Any system that emphasizes the use of techniques such as crop rotation, compost or manure application, and biological pest control in preference to synthetic inputs. Most certified organic farming schemes prohibit all genetically modified organisms and almost all synthetic inputs. Its origins are in a holistic management system that avoids off-farm inputs, but some organic agriculture now uses relatively high levels of off-farm inputs. Recognition and certification of organic agriculture may vary significantly across countries.

Other Effective Area-based Conservation Measures (OECM)
A geographically defined area other than a protected area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the *in situ* conservation of biodiversity (CBD, 2018a).

Overexploitation
Overexploitation means harvesting species from the wild at rates faster than natural populations can recover. Includes overfishing, and overgrazing.

P

Paired catchment
Paired catchment studies have been widely used to assess the likely impact of land use change on water yield around the world. Such studies involve the use of two catchments (drainage basins) with similar characteristics in terms of slope, aspect, soils, area, precipitation and vegetation located adjacent to each other. Following a calibration period, where both catchments are monitored, one of the catchments is subjected to treatment and the other remains as a control. This allows the climatic variability to be accounted for in the analysis. The change in water yield can then be attributed to changes in vegetation. The paired catchment studies reported in the literature can be divided into four broad categories: (i) afforestation experiments; (ii) regrowth experiments; (iii) deforestation experiments; and (iv) forest conversion experiments (Best *et al.*, 2003).

Palma ratio
The share of all income received by the 10% people with highest disposable income divided by the share of all income received by the 40% people with the lowest disposable income (OECD, 2018b).

Participatory methods
Participatory research methods are a variety of qualitative and quantitative methods "geared towards planning and conducting the research process with those people whose life-world and meaningful actions are under study" (Bergold & Thomas, 2012). Participatory methods acknowledge the possibility, the significance, and the usefulness of involving research partners in the knowledge-production process (Bergold, 2007).

Participatory process
Specific methods employed to achieve active participation by all members of a group in a decision-making process (Chatty *et al.*, 2003).

Particulate matter (PM)
A mixture of suspended solid particles and liquid droplets (dust, dirt, soot, or smoke) found in the air (US Environmental Protection Agency, 2018c); also referred to as particulate pollution.

Particulate organic carbon (POC)
The carbon content of particulate organic matter (Fiedler *et al.*, 2008).

Particulate organic matter
The large fraction (usually more than 7 micrometers) of soil organic matter (Fiedler *et al.*, 2008).

Pathways
In the context of the IPBES global assessment, trajectories toward the achievement of goals and targets for biodiversity conservation, the management of nature and nature's contributions to people, and, more broadly, the UN 2030 Sustainable Development Goals.

Patrimonial species
A rare or threatened species which needs local management and which may be a flagship species and may have cultural importance (Pervanchon, 2004).

Payments for ecosystem services (PES)
Payments for ecosystem services (PES) is a term used to describe a process whereas a beneficiary or user of an ecosystem service makes a direct or indirect payment to a provider of that service. PES involve a series of payments to land or other natural resource owners in return for a guaranteed flow of ecosystem services or certain actions likely to enhance their provision over-¬and-above what would otherwise be provided in the absence of payment (UNDP, 2018).

Peatland
Wetlands which accumulate organic plant matter *in situ* because waterlogging prevents aerobic decomposition and the much slower rate of the resulting anaerobic decay is exceeded by the rate of accumulation.

Pelagic
Occurring or living in open waters or near the surface with little contact with or dependency on the bottom (IUCN, 2012a).

People and Plants initiative
A collaboration initiated in 1992 between the World-Wide Fund for Nature (WWF), UNESCO-MAB and the Royal Botanic Gardens Kew on the promotion of ethnobotany and the equitable and sustainable use of plant resources.

Permafrost
Ground (soil or rock and included ice and organic material) that remains at or below 0°C for at least two consecutive years (IPCC, 2014a).

Persistent organic pollutants (POPs)
Organic compounds that are resistant to environmental degradation through chemical, biological, and photolytic processes. POPs persist in the environment for long periods, are capable of long-range transport, bioaccumulate in human and animal tissue and biomagnify in food chains, and have potentially significant impacts on human health and the environment. Exposure to POPs can cause serious health problems including certain cancers, birth defects, dysfunctional immune and reproductive systems, greater susceptibility to disease and even diminished intelligence (Stockholm Convention Secretariat, 2017).

Phenological shifts
Changes in species phenology, mostly as a result of climate change (Scranton & Amarasekare, 2017).

Phenology
The study of the relationship between climate and the timing of periodic natural phenomena such as migration of birds, bud bursting, or flowering of plants (IUCN, 2012a).

Phenotype
The characteristics of an individual resulting from interaction between its genotype (genetic constitution) and its environment (IUCN, 2012a). These characteristics often

include behaviour, physiology (e.g., oxygen consumption, heart rate), life history (e.g., body size, age, offspring number), or morphology (e.g., body proportions).

Phenotypic attributes (biodiversity)
A distinct variant of a phenotypic characteristic of an organism; it may be either inherited or determined environmentally, but typically occurs as a combination of the two (Lawrence, 2005).

Phenotypic plasticity
The capacity of a single genotype to exhibit a range of phenotypes in response to variation in the environment (Whitman & Agrawal, 2009).

Phylogenetic diversity
Although species richness is a commonly used measure of biodiversity, it fails to capture the reality that species without close relatives contribute more uniqueness than do species with many close relatives. Phylogenetic diversity is used as a general term for a range of measures that consider the total length of all the branches linking a set of species on their phylogeny ("evolutionary tree") and so reflect species' evolutionary uniqueness. One of the first such measures (Faith, 1992) is simply the sum of the branch lengths.

Phylum
A major taxonomic grouping of animals linked by having a similar general body plan and thought to be a clade. In plants the similar category is called a division (Lawrence, 2005).

Plankton
Aquatic organisms that drift or swim weakly. Phytoplankton are the plant forms of plankton (e.g., diatoms), and are the dominant plants in the sea. Zooplankton are the animal forms of plankton. Picoplankton are all forms of plankton which size is comprised between 0.2 and 2 micrometers (mostly bacteria) (Mullin, 2001).

Poaching
Animal killing or trapping without the approval of the people who controls or own the land (Survival International, 2018).

Pollination
The transfer of pollen from an anther to a stigma. Pollination may occur within flowers of the same plant, between flowers of the same plant, or between flowers of different plants (or combinations thereof) (IPBES, 2016).

Polycentric governance
An organizational structure where multiple independent actors mutually order their relationships with one another under a general system of rules. There are different types of polycentric governance arrangements. (Ostrom, 2010).

Polyphyletic taxon
A group composed of a collection of organisms in which the most recent common ancestor of all the included organisms is not included, usually because the common ancestor lacks the characteristics of the group. Polyphyletic taxa are considered "unnatural", and usually are reclassified once they are discovered to be polyphyletic (University of California Museum of Paleontology, 2009).

Population bottleneck
A decrease in the gene pool of the population due to an event that drastically reduces the size of that population, such as an environmental disaster, the hunting of a species to the point of extinction, or habitat destruction that results in the deaths of organisms. Due to the event, many alleles, or gene variants, that were present in the original population are lost and the remaining population has a very low level of genetic diversity (Nature, 2017).

Population genetic structure
The total genetic diversity and its distribution within and among a set of populations. It is shaped by many factors, including life history, population size, geographical or environmental barriers, gene flow, selection and population crashes or bottlenecks (Gilleard & Redman, 2016).

Pore-water pressure
The pressure exerted by a fluid phase in a porous medium (soil or rock) composed of a solid framework and pores filled or partially filled with water or other fluid (Reid, 2013).

Poverty
Poverty is, at the most basic level, a state of economic deprivation. Its manifestations include hunger and malnutrition, limited access to education and other basic services. Other corollaries of poverty are social discrimination and exclusion as well as the lack of participation in decision-making.

Primary vegetation
Vegetation in a particular plant assemblage that has not been subject to human disturbance, or has been so little affected that its natural structure, functions and dynamics have not undergone any change that exceed the elastic capacity of the ecosystem (IUCN, 2012a).

Prior, informed consent (PIC)
See 'Free, prior and informed consent (FPIC)'.

Private deforestation (see deforestation)
Deforestation occurring on private lands.

Protected area
A protected area is a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated values to people. There are multiple categories of protected areas, including and excluding people from within its boundaries.

Protected Area Downgrading, Downsizing and Degazettement (PADDD)
Refers to legal changes that ease restrictions on the use of a protected area, shrink a protected area's boundaries or eliminate legal protections entirely (Mascia & Pailler, 2011).

R

Reactive nitrogen
All biologically, photochemically, and/or radiatively active forms of nitrogen; a diverse pool of nitrogenous compounds that includes organic compounds (e.g., urea, amines, proteins, amides), mineral nitrogen forms, such as nitrates and ammonium, as well as gases that are chemically active in the troposphere (NOx, ammonia, nitrous oxide) and contribute to air pollution and the greenhouse effect (FAO, 2018a).

Rebound effect
The pattern by which resource users tend to compensate for improved efficiency by shifting behaviour towards greater consumption, which undermines apparent gains. For example, an increased fuel saving of motor vehicle tends to be compensated by spending more money on other resources or by driving more (Alcott, 2005).

Recruitment (species)
The influx of new members into a population by reproduction or immigration (IUCN, 2012a).

REDD+
(Reducing emissions from deforestation and forest degradation)
Mechanism developed by Parties to the United Nations Framework Convention on Climate Change (UNFCCC), which creates a financial value for the carbon stored in forests by offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development. Developing countries would receive results-based payments for results-based actions. REDD+ goes beyond simply deforestation and forest degradation, and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks.

Reduced impact logging (RIL)
The intensively planned and carefully controlled implementation of timber harvesting operations to minimize the environmental impact on forest stands and soils (FAO, 2018a).

Reforestation
Planting of forests on lands that have previously contained forests but that have been converted to some other use (IPCC, 2014a).

Regime
A long-term qualitative behaviour where the system's dynamics tend to stabilize, at different spatial and temporal scales in marine, terrestrial and polar systems (Rocha *et al.*, 2015).

Regime shift
Substantial reorganization in system structure, functions and feedbacks that often occurs abruptly and persists over time.

Remediation
Any action taken to rehabilitate ecosystems after their degradation.

Remote sensing
Methods for gathering data from a distance. In environmental studies and in monitoring, it usually refers to the use of satellite or airborne sensors to examine conditions and changes over large regions or landscape-scale analysis; often used in conjunction with Geographic Information Systems and often involves validation through on-the-ground activities (adapted from IUCN, 2012a).

Representation concentration pathways (RCPs)
Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover (IPCC, 2014a).

Resilience
The capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks (Walker *et al.*, 2004). A concept initially developed and applied in ecology, which progressively gained usage in the social and environmental sciences.

Restoration
Any intentional activities that initiates or accelerates the recovery of an ecosystem from a degraded state.

Re-wilding
The preservation of land with the goal of restoring natural ecosystem processes and reducing human control of landscapes (Gillson *et al.*, 2011) to allow declining populations to rebound.

Richness (biodiversity)
The number of distinct biological entities (typically species, but also genotypes, taxonomic genera or families, etc.) within a given sample, community, or area (Millenium Ecosystem Assessment, 2005).

S

Sacred groves
A particular type of sacred natural sites represented, for instance, by patches of forest revered as sacred (Bhagwat & Rutte, 2006). Sacred groves may be revered e.g., as burial grounds (Mgumia & Oba, 2003) or sites of ancestral or deity worship (Ramakrishnan *et al.*, 1998). There are locally-established rules that regulate how sacred groves can be used (Hughes & Chandran, 1998). Observation of those rules often contributes to the biodiversity conservation on those sites (Bhagwat & Rutte, 2006).

Sacred natural sites (SNS)
Areas of land or water that have special spiritual significance to peoples and communities (Verschuuren *et al.*, 2010). They consist of natural features, ranging from entire ecosystems, such as mountains, forests or islands, to single natural features such as a tree, spring or boulder, and are very important for the conservation of nature and culture. Sacred natural sites have been managed based on indigenous and local knowledge systems, developed over long periods of time, and are source of cultural identity.

Salinization
The process of increasing the salt content in soil is known as salinization. Salinization can be caused by natural processes such as mineral weathering or by the gradual withdrawal of an ocean. It can also come about through artificial processes such as irrigation.

Sea ice
Any form of ice found at sea which has originated from the freezing of sea water (sea ice does not include superstructure icing). Ice formed from the freezing of the waters of the Great Lakes will be considered the same as sea ice (NOAA's National Weather Service, 2009).

Seascape
The marine equivalent to landscape, which describes marine and coastal ecosystems defined primarily by their biological and environmental structure but also by ecosystem functioning, e.g., reefs shaped by corals living in symbiosis with microalgae and associated to a rich additional fauna comprising invertebrates and fish.

Second-growth forest
Regenerating forest after disturbance, such as fire or clear-cutting (IUCN, 2012a).

Sedimentary upper slope
Refers to the upper part of continental slopes. See 'Continental slope'.

Selection pressure
The effect of any feature of the environment that results in natural selection, e.g., food shortage, predator activity, competition from members of the same or other species (Lawrence, 2005).

Semi-natural habitats
An ecosystem with most of its processes and biodiversity intact, though altered by human activity in strength or abundance relative to the natural state.

Sense of place
Characteristics that make a place special or unique, as well as to those that foster a sense of authentic human attachment and belonging (Casey, 2001).

Sessile
Attached or stationary, as opposed to free-living or motile (Lawrence, 2005).

Shale gas
Natural gas from shale formations (European Commission, 2018).

Shamanism
A system that links people to the vital forces of nature, especially the soul or inner-self of non-humans or nature spirits, through the mediation of a specialist, the shaman. Shamans are generally trained through enduring experiences including the consumption of psychotropic substances that lead them to experience spiritual connections that are mobilized to combat illness and any dangers that may affect their community.

Shared socio-economic pathways (SSPs)
Shared Socio-economic Pathways (SSPs) describe alternative socio-economic futures in the absence of climate policy intervention, comprising sustainable development (SSP1), regional rivalry (SSP3), inequality (SSP4), fossil–fuelled development (SSP5) and middle-of-the-road development (SSP2). The combination of SSP-based socio-economic scenarios and Representative Concentration Pathway (RCP)-based climate projections provides an integrative frame for climate impact and policy analysis (IPCC, 2018).

Shelf ecosystems
See 'Continental shelf'.

Shifting cultivation
An agricultural system in which plots of land are cultivated temporarily, then abandoned to regenerate soil fertility by the regeneration of natural vegetation; the system can continue to produce food and materials even after abandoned. The system involves 1) the removal of the natural vegetation (usually forest or shrub land) in most cases (though not exclusively) by cutting and subsequent burning, mulching, or their combinations (such as in slash-and-burn, slash-and-mulch); 2) an alternation between a short duration of cultivation and a comparatively long duration of bush or forest fallow (such as in swidden agroforestry); and 3) the regular, in most cases cyclical, shifting of field (Erni, 2015). Shifting cultivation systems are found around the world, particularly in tropical areas, in a wide range of soils and vegetation types, under a diversity of land and resource management, using different crops and cultivation methods, and are practiced by innumerous Indigenous Peoples and Local Communities (Heinimann *et al.*, 2017; Nye & Greenland, 1960).

Slash-and-burn agriculture
See 'Shifting cultivation'.

Small-scale or non-industrial fisheries
Traditional fishing performed by family and/or community units rather than commercial units, using a relatively small amount of capital and energy, and carrying out short fishing trips close to coasts and mainly for local consumption (FAO, 2018a).

Social capital
As used in the global assessment, social capital refers to networks together with shared norms, values and understandings that facilitate co-operation within or among groups. Put together, these networks and understandings engender trust and so enable people to work together (OECD, 2007a). The term is also used in other ways, such as to refer to assets facilitating the achievement and/or maintenance of individual and family goals and privileges (Brondizio, *et al.*, 2009).

Social network
A network of social interactions and personal relationships.

Social norms
A social norm is what people in a group generally agree as shared expectations guiding individual and collective behaviour and action, that is, believed to be a typical action, an appropriate action, or both, and without necessarily representing a formal rule (adapted from Mackie *et al.*, 2015).

Social welfare
The condition of a society emphasizing happiness and contentment; social welfare relates to how individuals use their relationships to other actors in societies for their own and for the collective good; it has both material elements and wider spiritual and social dimensions (Adger, 2003).

Socio-ecological production landscapes and seascapes (SEPLS)
Dynamic mosaics of habitats and land uses where the harmonious interaction between people and nature maintains biodiversity while providing humans with the goods and services needed for their livelihoods, survival and well-being in a sustainable manner (IPSI, 2018).

Social-ecological system
A concept used in a variety of analytical approaches intended to examine the mutual and interdependent relationship between people and nature as inter-linked, recognizing that humans should be seen as a part of, not apart from, nature (Berkes & Folke, 1998), and nature as inter-linked to social systems (Ostrom 2009).

Soil compaction
An increase in density and a decline of porosity in a soil that impedes root penetration and movements of water and gases.

Soil degradation
An alteration of soil properties which cause negative effects on one or more soil functions, human health or the environment (ISO, 2013). Also see 'Habitat degradation' and 'Land degradation'.

Soil fertility
The capacity of a soil to receive, store and transmit energy to support plant growth. It is the component of overall soil productivity that deals with its available nutrient status, and its ability to provide nutrients out of its own reserves and through external applications for crop production (FAO, 2018c).

Soil organic matter (SOM)
Matter consisting of plant and/or animal organic materials, and the conversion products of those materials in soils (FAO & ITPS, 2015).

Species
An interbreeding group of organisms that is reproductively isolated from all other organisms, although there are many partial exceptions to this rule in particular taxa. Operationally, the term species is a generally agreed fundamental taxonomic unit, based on morphological or genetic similarity, that once described and accepted is associated with a unique scientific name (Millenium Ecosystem Assessment, 2005).

Species composition
The array of species in a specific sample, community, or area.

Species extirpation
The local extinction of a species.

Species traits
The morphological, physiological, phonological or behavioural characteristics of an organism, that typically inform about its response to the environment and effects

on the ecosystem (Lavorel & Garnier, 2002; Violle *et al.*, 2007).

Species-area relationship
A well-known strong empirical relationship between the area (A) of a region or patch of habitat and the number of species (S) it contains. Over most spatial scales, a power-law relationship S = cAz provides a good fit to data, with z often around 0.25 for separate sets of regions (known as the island species-area relationship) and 0.15 for nested parts of the same region (known as the continental species-area relationship). The species-area relationship has often been used to estimate the size of an extinction debt (qv) resulting from habitat loss (Rosenzweig, 1995).

Spillover effects/off-site effects
Human impacts or natural disturbances beyond system boundaries. These effects can be positive or negative, socioeconomic or/and environmental and can be much more profound than the effects within the focal system (Liu *et al.*, 2013).

Stability (social-ecological system)
The degree to which a system can continue to function if inputs, controls, or conditions are disrupted. It is a reflection of how minor a perturbation is capable of rendering the system inoperable or degraded; the types of perturbation to which the system is especially vulnerable; whether the system can "ignore" certain stresses; and the degree to which the system can be altered by surprise (Kerner & Thomas, 2014).

State (social-ecological system)
The collection of variables that describe the whole of the social–ecological system, including the attributes of ecosystem service providers and beneficiaries (Harrington *et al.*, 2010).

Stewardship practices
The responsible use and protection of the natural environment through conservation actions, active restoration and the sustainable use and management of resources (Bennett *et al.*, 2018).

Stratification (water column)
The formation of layers of water masses with different properties - salinity, oxygenation, density, temperature - that act as barriers to water mixing. These layers are normally arranged according to density, with the least dense water masses sitting above the more dense layers (Miller & Wheeler, 2012).

Subsistence agriculture
Farming system emphasizing production for use rather than for sale (FAO, 1998), but it may also involve some level of market-oriented production.

Succession (ecological)
The process whereby communities of plants, animals and microorganisms are replaced by others, usually more complex, over time as an area is colonized. Primary succession occurs on bare ground (e.g., after a volcanic eruption); secondary succession follows the interruption of a primary succession, e.g., after disturbances such as logging, ploughing or burning (Lawrence, 2005).

Sustainability
A characteristic or state whereby the needs of the present and local human population can be met without compromising the ability of future generations or populations in other locations to meet their needs (Millenium Ecosystem Assessment, 2005). There are multiple and complementary, and in cases conflicting, definitions of sustainability.

Sustainable community forestry
Forestry management strategies and practices designed to meet present needs of forest resource use without compromising the needs and options of future generations.

Sustainable development
Originally popularized by the UN report 'Our Common Future' (1987), it is intended to mean development that meets the needs and aspirations of the current generation without compromising the ability to meet those of future generations (Hesselink *et al.*, 2007).

Sustainable use
The use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations (Convention on Biological Diversity, 1992)

Swidden agriculture
See 'Shifting cultivation'.

Symbiosis
A long-term interaction between two species that can often have mutual benefit for both species (IUCN, 2012a).

T

Taboo
A social or religious custom prohibiting or restricting a particular practice or forbidding association with a particular person, place, species or behavior.

Taxon / taxonomic group
A category applied to a group in a formal system of nomenclature, e.g., species, genus, family etc. (plural: taxa).

Taxonomic diversity
Variety of species or other taxonomic categories (IUCN, 2012a).

Telecoupling
Socioeconomic-environmental interactions over distances (Liu *et al.*, 2013). It is an umbrella concept that encompasses various types of distant interactions, such as international trade, tourism, migration, foreign investment, species invasion, payments for ecosystem services, water transfer, information dissemination, knowledge transfer, and technology transfer (Liu *et al.*, 2015). Another related term is 'teleconnection'.

Tele-grabbing
Transboundary acquisition of land.

Tenure security
An agreement between an individual or group to land, resources, and residential property, which is governed and regulated by a legal and administrative framework and that may include both customary and statutory systems (Payne & Durand-Lasserve, 2012).

Territorial use rights in fisheries (TURFs)
The restriction of access to, and use of, a particular fishing ground or site to a group or an individual. This group, usually small in size, can determine how to harvest fish from the site and to whom the fish is allocated (Ward *et al.*, 2004).

Threatened species
In the IUCN Red List terminology, a threatened species is any species listed in the Red List categories Critically Endangered, Endangered, or Vulnerable.

Tidal flats
Intertidal, non-vegetated, soft sediment habitats, found between mean high-water and mean low-water spring tide datums and generally located in estuaries and

other low energy marine environments (Dineen, 2010).

Timber line
The altitude (in mountains) and latitude above which trees are unable to grow — also called tree line (Lawrence, 2005).

Tipping point
A set of conditions of an ecological and/or social-ecological system where further perturbation will cause rapid change and prevent the system from returning to its former state.

Total allowable catch (TAC)
The total catch allowed to be taken from a resource within a specified time period (usually a year) by all operators; designated by the regulatory authority. Usually allocated in the form of quotas (IUCN, 2012a).

Totemism
A principle or an ontology found within societies that differentiate different sections of the society, according to the attachment of these sections to animal or plant tutelar and ancestral spirits. In other words, totemism defines discontinuities in social order according to each group's attachment to a specific animal or plant spirit that is perceived as having similar features to this section (or clan) and an innerself that also ressembles people in this section (and reciprocally).

Traditional and community-based management systems
Resource management strategies and practices based on accumulated indigenous and local knowledge acquired through community-based learning processes and transmitted between successive generations, and implemented through community-based institutional arrangements.

Traditional ecosystem healing principles
Restoration and ecosystem management activities based on indigenous and local knowledge and often executed by Indigenous Peoples and Local Communities to restore and maintain the healthy functioning of ecosystems.

Traditional farming
A term used to refer to complex, diverse and locally-adapted agricultural systems, managed with time-tested through multi-generational experimentation, as well as diffusion of knowledge and practices. While the term 'traditional' is used to refer to a persisting long-term farming system, it does not intend to imply that such systems are static (see Altieri & Koohafkan, 2008).

Transformability (part of resilience)
The capacity to cross thresholds, enter new development trajectories, abandon unsustainable actions and chart better pathways to established targets (Folke *et al.* 2010).

Transformative change
A fundamental, system-wide reorganization across technological, economic and social factors, including paradigms, goals and values (IPBES, 2018; IPCC, 2018).

Trophic level
The level in the food chain in which one group of organisms serves as a source of nutrition for another group of organisms (e.g., primary producers, primary or secondary consumers, decomposers).

Trophic transfer
The transport of contaminants between two trophic levels (Suedel *et al.*, 1994).

U

Units of Analysis
In the context of IPBES, a broad-based classification system of terrestrial, freshwater and marine systems at the global level, considering both the state of nature in classes equivalent to 'biomes', and classes where ecosystem structure and function have been severely altered through human management, which can be called 'anthropogenic biomes' or 'anthromes'. Seventeen units of analysis have been identified by IPBES to serve as a framework for comparison within and across assessments and represent a pragmatic solution. The IPBES units of analysis are not intended to be prescriptive for other purposes than those of IPBES assessments. They are likely to evolve as the work of IPBES develops (see chapter 1).

Upscaling
See 'Downscaling'.

Upwelling
A process in which deep, cold water rises toward the surface replacing warmer water pushed away by winds. Water that rises to the surface as a result of upwelling is typically colder and rich in nutrients, which "fertilize" surface waters, meaning that these surface waters often have high biological productivity (NOAA, 2018e).

Urban ecosystems
Any ecological system located within a city or other densely settled area or, in a broader sense, the greater ecological system that makes up an entire metropolitan area (Pickett, 2015).

Urban metabolism
A method to evaluate the flows of energy and materials within an urban system, which can provide insights into the system's sustainability and the severity of urban problems such as the impact of excessive social, community, and household metabolism at scales ranging from global to local (Zhang *et al.*, 2015).

Urbanization
The increase in the proportion of a population living in urban areas; the process by which a large number of people becomes permanently concentrated in relatively small areas, forming cities (OECD, 2001c).

V

Values
- **Value systems:** Set of values according to which people, societies and organizations regulate their behaviour. Value systems can be identified in both individuals and social groups (Pascual *et al.*, 2017).
- **Value (as principle):** A value can be a principle or core belief underpinning rules and moral judgments. Values as principles vary from one culture to another and also between individuals and groups (IPBES/4/INF/13).
- **Value (as preference):** A value can be the preference someone has for something or for a particular state of the world. Preference involves the act of making comparisons, either explicitly or implicitly. Preference refers to the importance attributed to one entity relative to another one (IPBES/4/INF/13).
- **Value (as importance):** A value can be the importance of something for itself or for others, now or in the future, close by or at a distance. This importance can be considered in three broad classes. 1. The importance that something has subjectively, and may be based on experience. 2. The importance that something has in meeting objective needs. 3. The intrinsic value of something (IPBES/4/INF/13).
- **Value (as measure):** A value can be a measure. In the biophysical sciences,

any quantified measure can be seen as a value (IPBES/4/INF/13).

- **Non-anthropocentric value:** A non-anthropocentric value is a value centered on something other than human beings. These values can be non-instrumental or instrumental to non-human ends (IPBES/4/INF/13).
- **Intrinsic value:** This concept refers to inherent value, that is the value something has independent of any human experience or evaluation. Such a value is viewed as an inherent property of the entity and not ascribed or generated by external valuing agents (Pascual *et al.*, 2017).
- **Anthropocentric value:** The value that something has for human beings and human purposes (Pascual *et al.*, 2017).
- **Instrumental value:** The value attributed to something as a means to achieving a particular end (Pascual *et al.*, 2017).
- **Non-instrumental value:** The value attributed to something as an end in itself, regardless of its utility for other ends.
- **Relational value:** The values that contribute to desirable relationships, such as those among people or societies, and between people and nature, as in "Living in harmony with nature" (IPBES/4/INF/13).
- **Integrated valuation:** The process of collecting, synthesizing, and communicating knowledge about the ways in which people ascribe importance and meaning of nature's contributions to humans, to facilitate deliberation and agreement for decision making and planning (Pascual *et al.*, 2017).

(see chapter 1 for more details)

W

Water footprint
The water footprint measures the amount of water used to produce each of the goods and services we use. It can be measured for a single process, such as growing rice, for a product, such as a pair of jeans, for the fuel we put in our car, or for an entire multi-national company. The water footprint can also tell us how much water is being consumed by a particular country – or globally – in a specific river basin or from an aquifer (Hoekstra *et al.*, 2011).

Water grabbing
A situation where powerful actors are able to take control of, or reallocate to their own benefits, water resources already used by local communities or feeding aquatic ecosystems on which their livelihoods are based (Mehta *et al.*, 2012).

Water stress
Water stress occurs in an organism when the demand for water exceeds the available amount during a certain period or when poor quality restricts its use (European Environment Agency, 2018).

Water use efficiency
The ratio between effective water use and actual water withdrawal. In irrigation, it represents the ratio between estimated plant water requirements (through evapotranspiration) and actual water withdrawal (FAO, 2018a).

Welfare
See 'Social welfare'.

Wellbeing (human)
A perspective on a good life that comprises access to basic resources, freedom and choice, health and physical, including psychological, well-being, good social relationships, security, equity, peace of mind and spiritual experience. Well-being is achieved when individuals and communities can act meaningfully to pursue their goals and can enjoy a good quality of life. The concept of human well-being is used by many countries and societies. In the context of IPBES' conceptual framework, it is used complementary and together with living in harmony with nature, and living well in balance and harmony with Mother Earth. All these are different perspectives on a good quality of life (see chapter 1).

Wetlands
In the context of IPBES, wetlands are permanent or temporary freshwater, brackish and marine areas (floodplains, bogs, swamps, marshes, estuaries, deltas, peatlands, potholes, vernal pools, fens and other types, depending on geography, soil, and plant life) where water covers the soil, or is present either at or near the surface of the soil all year or for varying periods of time during the year. A division was made between inland waters (lakes, rivers, reservoirs) and wetlands.

Wild habitat
See 'Natural habitat'.

Wild relative
Wild species related to crops, including crop progenitors (FAO, 2018a).

Wilderness
Ecosystems, landscapes and seascapes with a very low degree of human influence, at present with full recognition that they are often inhabited and managed by people, and have been so for centuries or millennia, often at low population densities, and therefore their native biodiversity and ecological and evolutionary processes have not been reconfigured by human drivers to a significant degree (Kormos *et al.*, 2017; Potapov *et al.*, 2017; Watson *et al.*, 2016). Not all areas designated as wilderness conform to this definition, especially in Europe where abandoned agricultural areas 'managed' by 'wild living' large herbivores are also called wilderness. Some wilderness areas in the world show transition to cultural landscapes with low human influence.

Willingness-to-accept
Estimate of the amount people are prepared to accept in exchange for a certain state or good (e.g., WTA for protection of an endangered species) (IUCN, 2012a).

Willingness-to-pay
Estimate of the amount people are prepared to pay in exchange for a certain state or good (e.g., WTP for protection of an endangered species) (IUCN, 2012a).

Worldviews
Worldviews are defined by the connections between networks of concepts and systems of knowledge, values, norms and beliefs. Individual person's worldviews are molded by the community(ies) the person belongs to. Practices are embedded in worldviews and are intrinsically part of them, such as through rituals, institutional regimes, social organization, but also in environmental policies, in development choices, among others.

Z

Zoonotic disease
Zoonotic disease or zoonoses are directly transmitted from animals to humans via various routes of transmission (e.g., air - influenza; bites and saliva - rabies).

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ANNEX II
Acronyms

ABNJ	Area Beyond National Jurisdiction
ABS	Access and Benefit Sharing
AIDS	Acquired Immune Deficiency Syndrome
BaU	Business as Usual
BECCS	Bioenergy in combination with Carbon Capture and Storage
BII	Biodiversity Intactness Index
BOD	Biochemical Oxygen Demand
BVOC	Biogenic Volatile Organic Compounds
CAFF	Conservation for the Arctic Flora and Fauna
CAML	Census of Antarctic Marine Life
CBD	Convention on Biological Diversity
CBI	City Biodiversity Index
CCAMLR	Convention on the Conservation of Antarctic Marine Living Resources
CCRF	Code of Conduct for Responsible Fisheries (FAO)
CCS	Carbon Capture and Storage
CEMP	CCAMLR Ecosystem Monitoring Program
CFC	Chlorofluorocarbon
CH_4	Methane
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMS	Convention on the Conservation of Migratory Species of Wild Animals
CO_2	Carbon dioxide
COP	Conference of parties
CR	Critically Endangered (IUCN category)
CSR	Corporate Social Responsibilty
CWR	Crop Wild Relatives
DALY	Disability Adjusted Life-Year
DD	Data Deficient (IUCN category)
DDT	Dichlorodiphenyltrichloroethane
DGVM	Dynamic Global Vegetation Model
DMC	Domestic Material Consumption
DRC	Democratic Republic of Congo
EBSA	Ecologically or Biologically Significant Area
EBV	Essential Biodiversity Variables
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EJ	Exajoules
EKC	Environmental Kuznets Curve
EMRIP	Expert Mechanism on the Rights of Indigenous Peoples
EN	Endangered (IUCN category)
EPI	Environmental Performance Index
ESA	European Space Agency
ESH	Extent of Suitable Habitat
ESM	Earth System Model
ET	Evapotranspiration
EU	European Union
EVD	Ebola Virus Disease
EW	Extinct in the Wild (IUCN category)
FAO	Food and Agriculture Organization
FLEGT	Forest Law Enforcement, Governance and Trade (EU)
FPIC	Free, Prior and Informed Consent
FSC	Forest Stewardship Council
GA	Global Assessment
GBIF	Global Biodiversity Information Facility
GBA	Global Biodiversity Assessment
GBO	Global Biodiversity Outlook
GDP	Gross Domestic Product
GEF	Global Environment Facility
GEO	Global Environmental Outlook
GEO BON	Group on Earth Observations Biodiversity Observation Network
GHa	Gigahectares
GHG	Green House Gases
GIS	Geographic Information System
GMO	Genetically Modified Organism
GQL	Good Quality of Life
GtC	Gigatons of Carbon
GW	Gigawatts
HAB	Harmful Algal Bloom
HANPP	Human Appropriation of Net Primary Production
HDI	Human Development Index
HFC	Hydrofluorocarbon
HIV	Human Immunodeficiency Virus
IAMs	Integrated Assessment Models
IAS	Invasive Alien Species
IBA	Important Bird and Biodiversity Area
IBP	International Biological Program
ICCA	Indigenous Peoples and Community Conserved Territories and Areas

ICCWC International Consortium on Combating Wildlife Crime
ICM Integrated Coastal Management
IEA International Energy Agency
IFAD International Fund for Agricultural Development
IFOAM International Federation of Organic Agriculture Movements
IIFB International Indigenous Forum on Biodiversity
ILK Indigenous and Local Knowledge
IMO International Maritime Organization
IOC Intergovernmental Oceanographic Commission (UNESCO)
IPBES Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC Intergovernmental Panel on Climate Change
IPLC Indigenous Peoples and Local Communities
IPM Integrated Pest Management
IPPC International Plant Protection Convention
IPSI International Partnership for the Satoyama Initiative
ISSWM Integrated Sustainable Solid Waste Management
ITPGRFA International Treaty on Plant Genetic Resources for Food and Agriculture
ITQ Individual Transferable Quotas
IUCN International Union for Conservation of Nature
IUU Illegal, Unreported, and Unregulated
IWRM Integrated Water Resources Management
IWT Illegal Wildlife Trade
LC Least Concern (IUCN category)
LCA Life Cycle Assessment
LPI Living Planet Index
LSLA Large-Scale Land Acquisitions
LUCC Land Use and Land Cover Change
MA Millenium Ecosystem Assessment
MAB Man and the Biosphere Programme
MDG Millenium Development Goals
MEAs Multilateral Environmental Agreements
MIKE Monitoring the Illegal Killing of Elephants (CITES)
MLS Multilateral System
MPA Marine Protected Areas
MPI Multidimensional Poverty Index
MSA Mean Species Abundance
MSC Marine Stewardship Council
MSP Marine Spatial Planning
MSY Maximum Sustainable Yield
NBSAP National Biodiversity Strategies and Action Plans
NCP Nature's Contributions to People
NDC Nationally Determined Contributions
NF3 Nitrogen Trifluoride
NGOs Non-governmental organizations
NH_3 Ammonia
NO_3 Nitrate
NO_x Nitrogen Oxides
NPP Net Primary Production
NT Near Threatened (IUCN category)
NTFP Non-timber Forest Product
OBIS Ocean Biogeographic Information System
ODA Official Development Assistance
OECD Organisation for Economic Cooperation and Development
OECM Other Effective Area-Based Conservation Measures
OIE World Organisation for Animal Health
OMZ Oxygen-Minimum Zone
OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic
PADDD Protected Area Downgrading, Downsizing and Degazettement
PAs Protected Areas
PEFC Programme for the Endorsement of Forest Certification
PES Payment for Ecosystem Services
PFC Perfluorocarbon
PgC Petagrams of Carbon
PJ Petajoules
PM Particulate Matter
POC Particulate Organic Carbon
POP Persistent Organic Pollutants
PPP Purchasing Power Parity
PSMA Agreement on Port State Measures
RCP Representative Concentration Pathways
REDD+ Reducing Emissions from Deforestation and Forest Degradation
RFMO/A Regional Fisheries Management Organizations or Arrangements
RIL Reduced Impact Logging
RLI Red List Index
RSPO Roundtable on Sustainable Palm Oil
RTRS Roundtable on Responsible Soy
SDG (the United Nations 2030) Sustainable Development Goals
SDM Species Distribution Models
SEEA System of Environmental and Economic Accounting
SEPLS Socio-Ecological Production Landscapes and Seascapes
SF6 Sulfur Hexafluoride
SFSC Short Food Supply Chains
SLR Sea Level Rise
SM Supplementary Material
SMTA Standard Material Transfer Agreement

SO_2 Sulfur Dioxide
SOC Soil Organic Carbon
SPM Summary for Policy Makers
SRES Special Report on Emission Scenarios (IPCC)
SSF Small-Scale Fisheries
SSF-VG Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication
SSP Shared Socioeconomic Pathways
SUWM Sustainable Urban Water Management
TEEB The Economics of Ecosystems and Biodiversity
TRAFFIC Wildlife Trade Monitoring Network
TURF Territorial Use Rights in Fisheries
TWIX Trade in Wildlife Information Exchange (EU)
UN United Nations
UNCCD United Nations Convention to Combat Desertification
UNCLOS United Nations Convention on the Law of the Sea
UNCTAD United Nations Conference on Trade and Development
UNDP United Nations Development Programme
UNDRIP United Nations Declaration on the Rights of Indigenous Peoples
UNEA United Nations Environment Assembly (UNEP)
UNEP United Nations Environment Programme
UNEP-WCMC United Nations Environment Programme-World Conservation Monitoring Centre
UNESCO United Nations Educational, Scientific and Cultural Organization
UNFCCC United Nations Framework Convention on Climate Change
UNFSA United Nations Fish Stocks Agreement
UNGA United Nations General Assembly
UNICEF United Nations International Children's Emergency Fund
UNPFII United Nations Permanent Forum on Indigenous Issues
UoA Units of Analysis
USD United States Dollar
US-EPA United States Environmental Protection Agency
VME Vulnerable Marine Ecosystem
VPA Voluntary Partnership Agreement
VU Vulnerable (IUCN category)
WBCSD World Business Council for Sustainable Development
WHC World Heritage Convention
WHI World Happiness Index
WHO World Health Organization
WHS World Heritage Site
WRI World Resource Institute
WTO World Trade Organization
WWAP World Water Assessment Programme (UNESCO)
WWF World Wide Fund for Nature (also known as World Wildlife Fund)

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ANNEX V
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