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)

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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.

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),

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[1] Value adjusted to 2015 United States dollars taking into account inflation only.

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}.

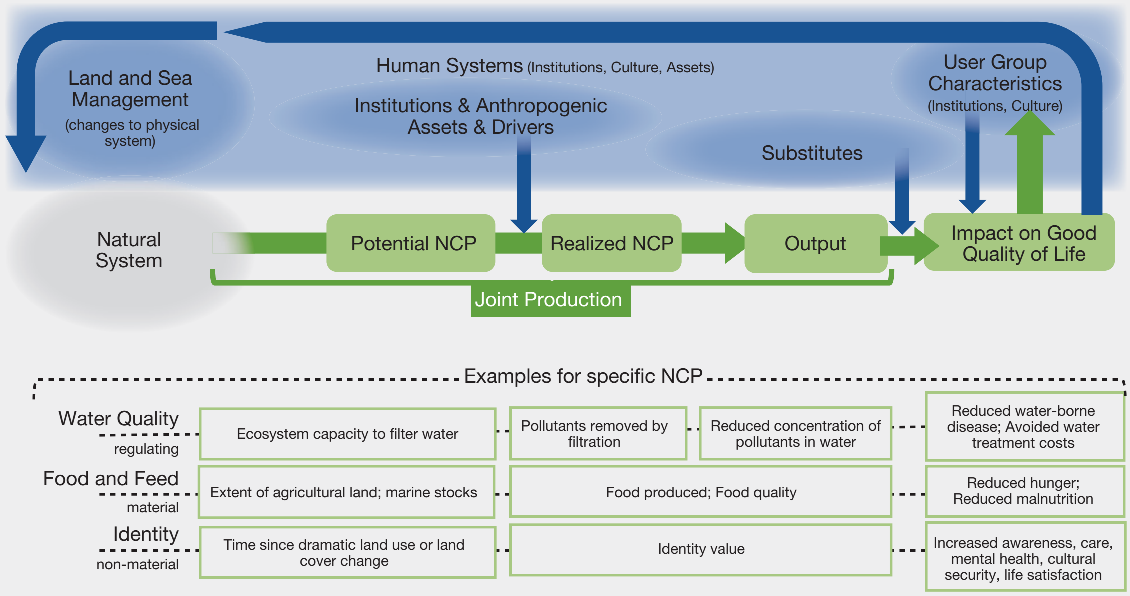
16 Studies linking co-production and impact on quality of life are scarce. For some NCP, there is a gap between what is commonly measured for the output of co-production and what is most important for impact on good quality of life. Assessing the impact on good quality of life requires synthesis and 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



Water Quality regulating	Ecosystem capacity to filter water	Pollutants removed by filtration	Reduced concentration of pollutants in water	Reduced water-borne disease; Avoided water treatment costs
Food and Feed material	Extent of agricultural land; marine stocks	Food produced; Food quality		Reduced hunger; Reduced malnutrition
Identity non-material	Time since dramatic land use or land cover change	Identity value		Increased awareness, care, mental health, cultural security, life satisfaction

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

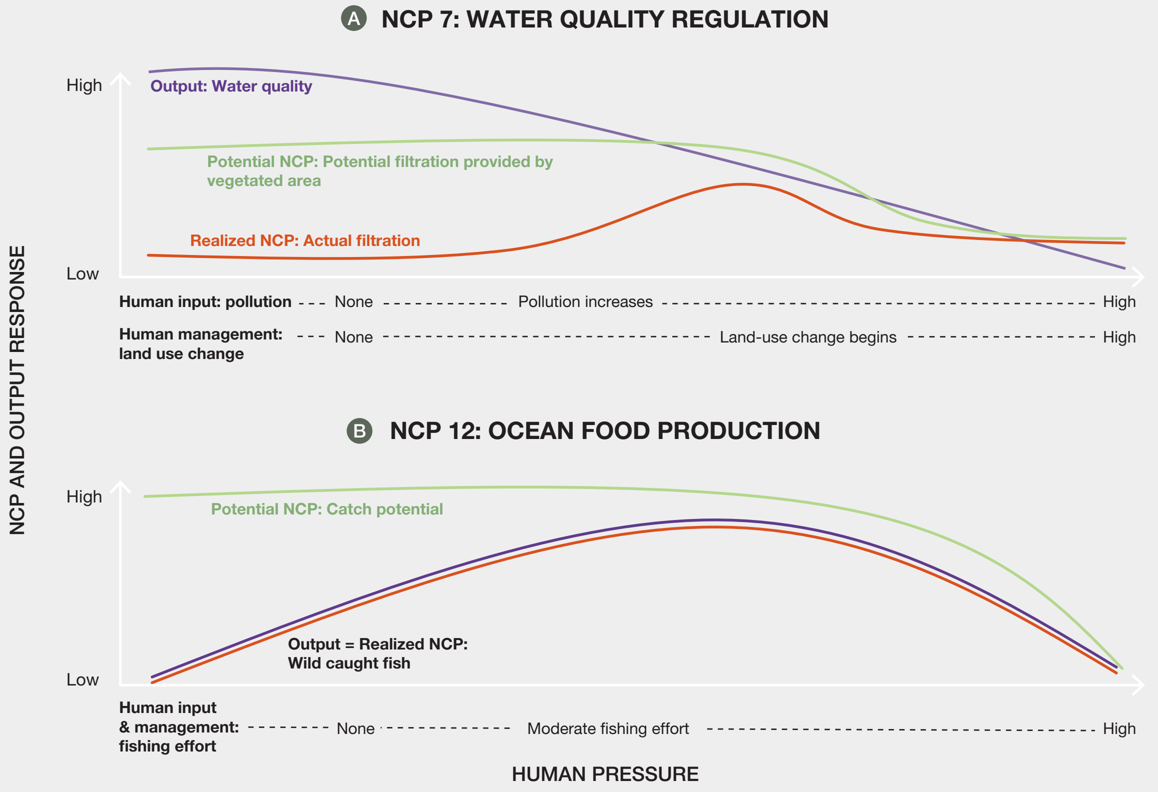


Figure ② ③ ② **Response of Potential NCP, Realized NCP, and NCP Output to External Pressures.**

Examples of changes in local co-production of potential NCP, realized NCP, and the output as human pressure increases. In Ⓐ, 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 Ⓑ, 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.

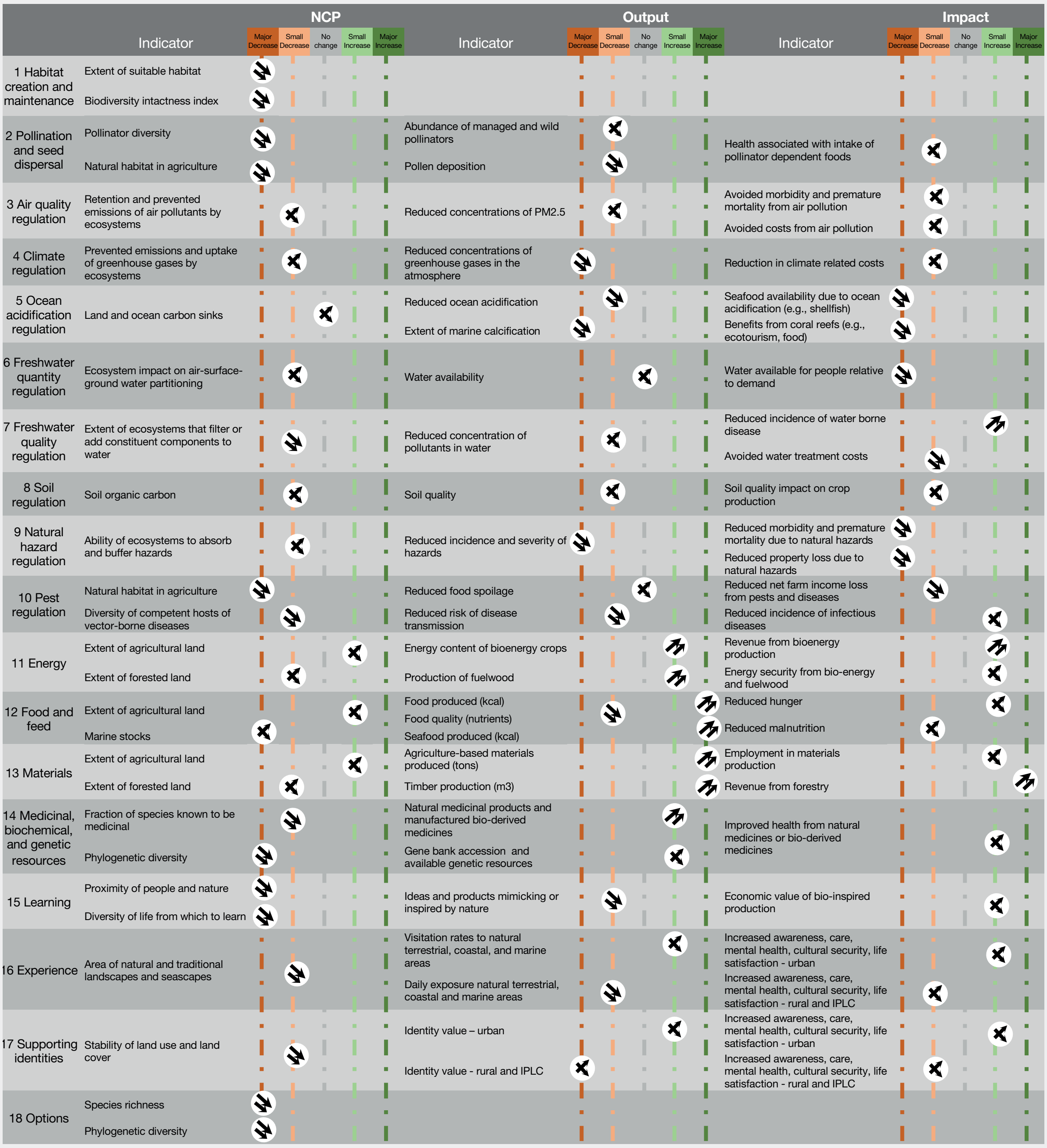


Figure ② ③ ③ Global trends in potential NCP, output, and impact on good quality of life by 18 NCP.

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),

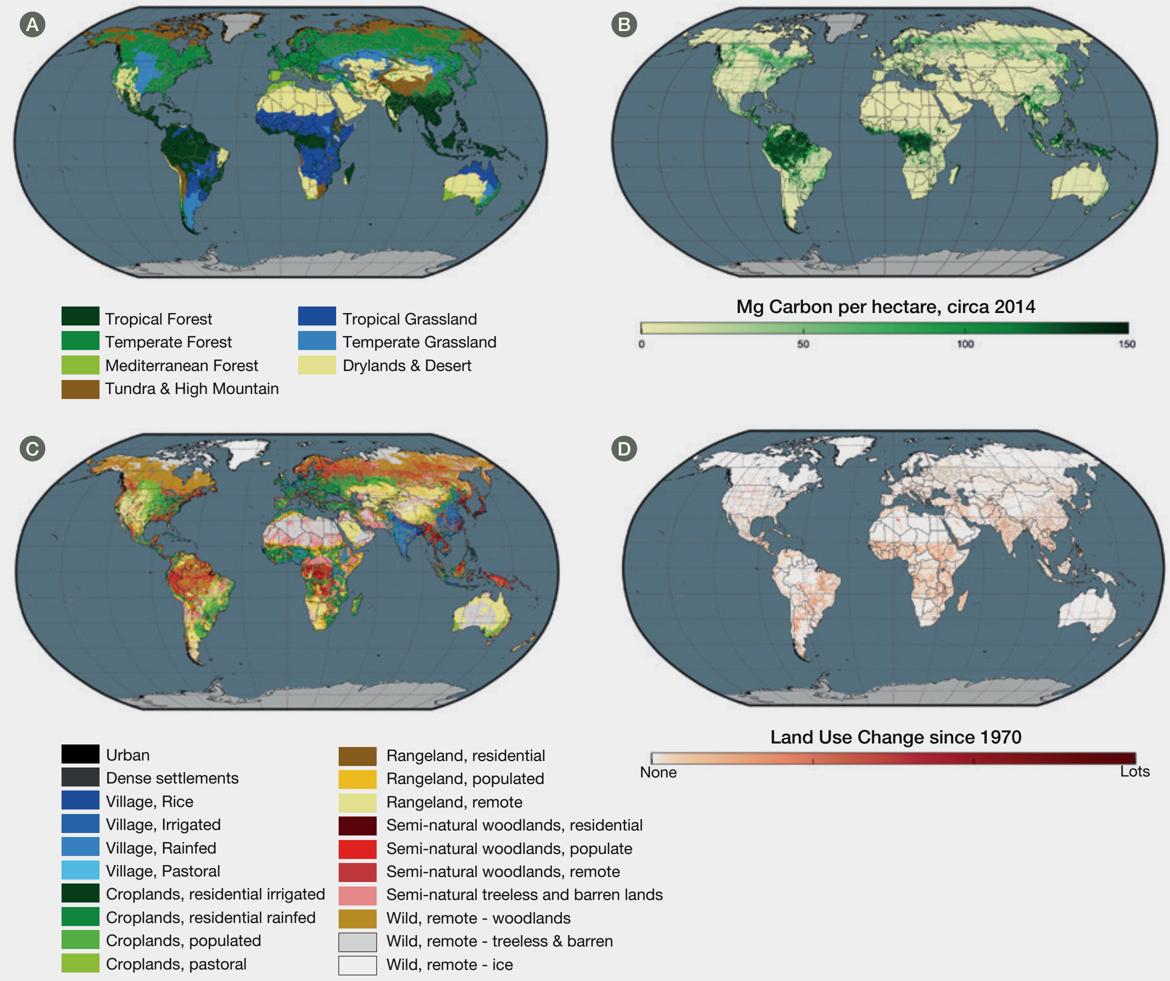


Figure ② ③ ④ **Global Distribution of Selected Indicators Relevant to NCP.**

Across terrestrial biomes globally Ⓐ, 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 Ⓑ. 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 Ⓒ. Global land uses Ⓓ**.** 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.,*

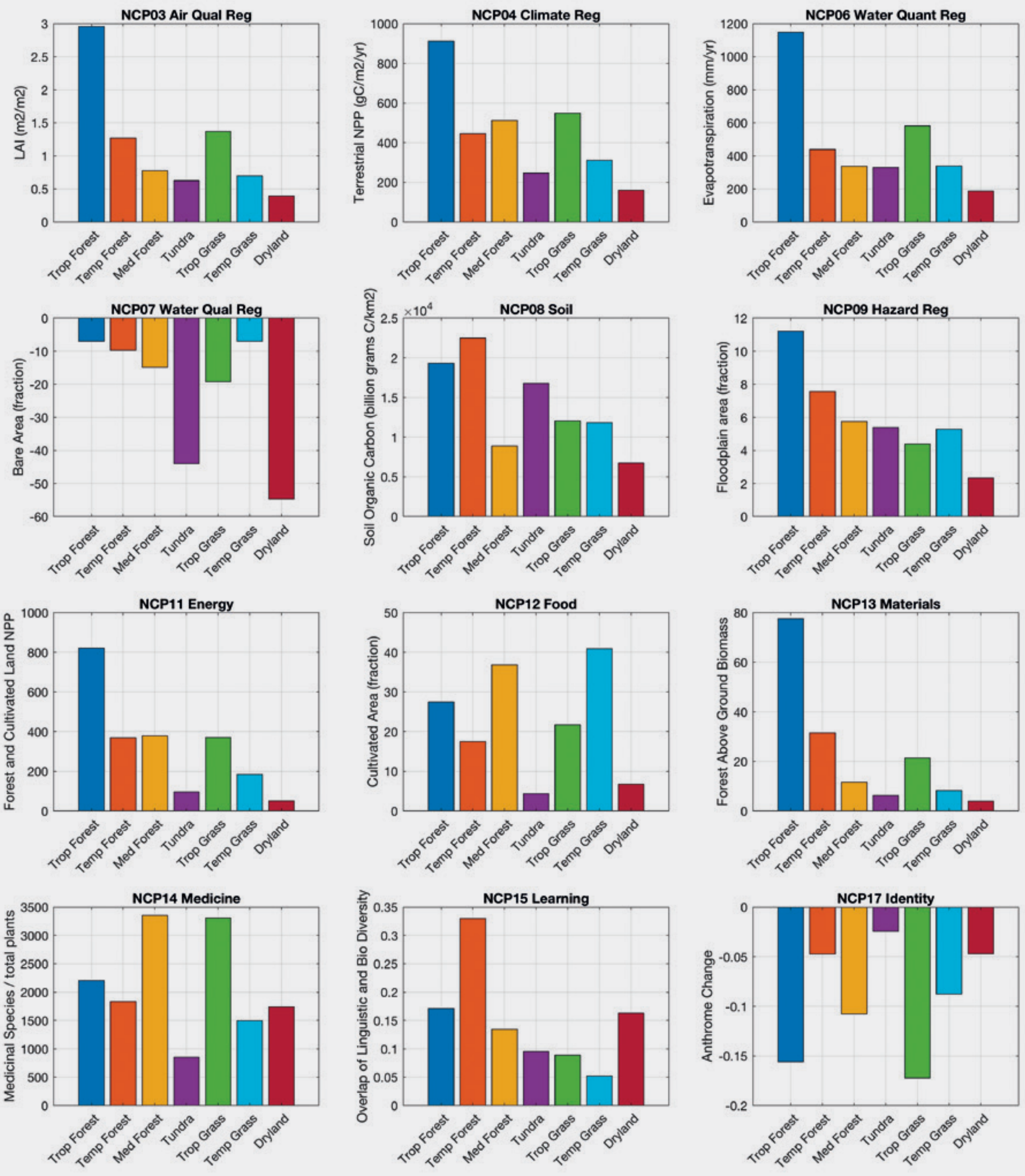


Figure ② ③ ⑤ **Global Distribution of Data Proxies Relevant to Selected Potential NCP.**

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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