IPBES Global assessment – Chapter 2.3 Supplementary materials

Contents

APPENDIX 1 – Indigenous and Local Knoweldge Contributions

Contributing Authors on ILK (Appendix 1)

1. **Vanesse Labeyrie**
NCP Climate Regulation: Local knowledge on climate change, adaptation and mitigation

2. **Matthew Lauer**, Professor, Department of Anthropology, San Diego State University
NCP Hazards: Indigenous Knowledge, Hazards, and Extreme Events

3. **Aibek Samakov**, Fellow IPBES
NCP Soils: ILK on sediment retention, erosion control and soil formation.

Other contributions by Contributing Authors focusing on ILK (Appendix 2)

4. **Lucia Chamlian Munari, Cristina Adams, Andreas Heinimann**
NCP Food and Feed. Shifting cultivation (see Appendix 2, NCP Food and Feed)

5. **Mathieu Salpeteur** (see Appendix 2, NCP Food and Feed)
Contribution of food from pastoralism in general and nomad pastoralism to good quality of life globally and across regions and social groups

1. Local knowledge on climate change, adaptation and mitigation

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Indigenous people (IP) are approximatively 370 million people and occupy about 38 million km2 in 87 countries (Garnett et al., 2018), mostly in Africa, Asia, and Latin America. IP are in majority settled in areas experimenting the strongest negative impacts of climate change (Pachauri et al., 2014), i.e: arctic areas and tundra, tropical areas, coastal areas and small islands. These impacts encompass temperature increase between +1 and +2.5 °C over the period 1901-2012, rainfall decrease up to -100 mm/yr per decade, increase frequency of extreme climatic events, sea level rise, and loss of biodiversity. Climate change hence affects negatively IPs' health through physical harms due to extreme events (cyclones, flooding, and high temperature), increased prevalence of diseases, food insecurity, decrease of water availability and quality, and it has psychological impacts (Ford, 2012). Climate change impact on food security is especially a key issue for the majority of IP, who are living in rural communities that base their livelihood on natural resources. Their main activities are especially small-scale farming and herding, hunting, fishing, and collecting timber and non-timber products, which are all deeply affected by climate change (Pachauri et al., 2014). Small-scale agriculture is especially the pillar of IP livelihoods in tropical regions. It represents about 380 million households in Africa, Asia and Latin America and produces more than 70% of the food calories in these regions. It also produces more than half of the food calories at the global scale (Samberg, 2016). Small-scale fisheries are crucial in the livelihood of about 3.5 million indigenous people in the coastal areas (Cisneros-Montemayor et al., 2016). Timber and non-timber products support the livelihoods of about 1 - 1.7 billion people who rely on forest or agroforests, among which 200 million of indigenous people depending primarily on natural forest (Chao, 2012). Through its negative effect on these activities, climate change hence affects the livelihood of millions of IP.

Nevertheless, these communities developed over time a deep knowledge to adapt to climatic variations in the highly exposed areas where they live, with differences among cultures (Adger et al., 2013). Such diversity of local knowledge is a key asset for improving our understanding of climate change, and thus for the adaptation of human societies (Reyes-García et al., 2016). Local knowledge is especially instrumental in: i. limiting biophysical and social exposure, ii. reducing sensitivity to change and variability, iii. increasing adaptive capacity and adaptation processes (Naess, 2013). Local communities first possess a large body of knowledge on weather and climate prediction based on the observation of their environment, and these forecasts are instrumental for preparing to climatic events such as droughts or heavy rainfalls (Kronik and Verner, 2010; Nyong et al., 2007). They also possess deep knowledge on how to adapt to climate change, which encompass a variety of domains that can be clustered under (Lebel, 2013): i. natural resources management, ii. physical infrastructures, iii. livelihood strategies, and iv. social institutions (Agrawal et al., 2008). Local communities especially developed over time a large body of knowledge on the management of the diversity of biological resources, being in agroecosystems or more widely in landscapes (Altieri and Nicholls, 2013; Schippers et al., 2015). For instance, agroforestry is largely practiced by rural communities in South America (3.2 million km2), sub-Saharan Africa (1.9 million km2), and Southeast Asia (1.3 million km2), who manage complex associations of plants for increasing their resilience to inter-annual climatic variations and adapt to temperature increase or rainfall decrease (Verchot et al., 2007; Zomer et al., 2009). However, the extent and rapidity of climate change now put at risk these adaptation strategies because disturbances of the annual climatic calendar result in the disruption of the agricultural calendars (Kronik and Verner, 2010).

IP and local communities also play a pivotal role in climate change mitigation. Indeed, indigenous people are mostly settled in ecosystems of high potential for mitigation, i.e conservation areas that include mature forests and coastal ecosystems, and agricultural lands (Garnett et al., 2018). Furthermore, they developed practices that prove to be instrumental for mitigation through enhancing carbon storage and limiting GHG emissions. First, IP developed practices that increase carbon sequestration through tree conservation in areas with a low anthropization level, such as communal forest reserves (Nyong et al., 2007). Secondly, they also contribute to carbon sequestration in agroecosystems through agroforestry or some types of fallow cultivation, but also through zero tilling, mulching, application of green manure, intercropping, and other soil management techniques that contribute to increase carbon storage in soils. Last, they limit the release of GHG as they mostly practice organic farming with a limited uses of chemical fertilizers and pesticides (Altieri and Nicholls, 2013). A large proportion of IP and LC in the tropical region especially practice agroforestry (Zomer et al., 2009), which is an especially interesting practice for mitigation regarding its high carbon sequestration potential that is estimated to range between 2.6, and 10 Mg C/ha/yr from the semi-arid to humid regions (Altieri and Nicholls, 2013). However, IP may have also practices that are detrimental regarding mitigation objectives. It may be the case for instance of some types of irrigated rice fields, or short-fallow shifting cultivation, but much debate exist on this question because of the huge diversity of these practices and the lack of estimations accounting for the carbon balance of at the social-ecological system scale (Scheidel, 2018).

Overall, local ecological knowledge is declining at the global scale as a result of globalization, modernization, and market integration (Aswani et al., 2018), and this likely concerns climate change domain as well. According to this survey, local agricultural knowledge, which is instrumental for both adaptation and mitigation, is experimenting an especially dramatic erosion. This global homogenization of knowledge threatens the capacity of humans to adapt and mitigate climate change, as hybridization between local and scientific knowledge is recognized as crucial to tackle environmental management questions (Armitage et al., 2009; Berkes, 2009a). Hence, rather than opting for a the "static" conservation of local knowledge, public policies should rather support local institutions and relational networks that allow the generation of local knowledge, and its hybridization with other exogenous knowledge sources (Berkes, 2009b; Berkes and Ross, 2013).

Google Scholar search criteria:

1. (("climate change" OR "climate variations") AND ("holistic knowledge" OR "indigenous knowledge" OR "traditional knowledge" OR "local knowledge")) AND (review OR "meta-analysis"): 16 300 results
2. (("climate change" OR "climate variations") AND ("mitigation" or "adaptation") AND ("holistic knowledge" OR "indigenous knowledge" OR "traditional knowledge" OR "local knowledge")) AND (review OR "meta-analysis"): 17 200 results
3. (("climate change" OR "climate variations") AND ("resilience" OR "coping strategies" OR "adaptation") AND ("landscape diversity" OR "landscape heterogeneity")) AND (review OR "meta-analysis"): 3 200 results

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2. Indigenous Knowledge, Hazards, and Extreme Events

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Starting in the 1970s and 80s the limitations of top-down approaches to disaster risk reduction and mitigation led to increased interest in participatory and community-based initiatives (Dekens 2007). There was growing awareness that in many contexts local or indigenous people had sophisticated, empirically based knowledge of their local ecosystems that could be drawn upon to reduce community vulnerability to environmental hazards (Mercer et al. 2010; Hiwasaki et al. 2014). With their intimate reliance on the local environment for their livelihoods, it comes as no surprise that indigenous people have built up a rich corpus of knowledge and practices to respond to resource fluctuations or acute environmental perturbations. Interest in indigenous ecological knowledge (IEK) among disaster researchers was also propelled by new, more accurate theoretical frameworks that emphasized the entangling of physical hazard risk with human, societal, and cultural, and political factors (Wisner 2004) as well as the rise of climate change and the associated risks (Field et al. 2012). Rather than mitigating risk to biophysical hazards, emphasis is now also placed on reducing and minimizing social and political vulnerability.

IEK went mainstream after the 2004 Indian Ocean Tsunami. Several widely publicized cases documented how indigenous communities in the Indian Ocean region drew from traditional myths and oral history about past tsunamis to respond and survive the disaster (Adger et al. 2005; McAdoo et al. 2006; Arunotai 2008). This kind of intergenerationally transmitted information is well documented across the globe. Studies have revealed how communites have knowledge about their responses to past ecological shocks such as tsunamis (Becker et al. 2008; McAdoo, Moore, and Baumwoll 2009; Lauer 2012; Walshe and Nunn 2012); fire (Bradstock, Williams, and Gill 2012); extreme weather (Janif et al. 2016); cyclones (Yates and Anderson-Berry 2004; Paul and Routray 2013; Veland, Howitt, and Dominey-Howes 2010); floods (Mavhura et al. 2013; Paul and Routray 2010); heavy rain (Roncoli, Ingram, and Kirshen 2002; Chang'a, Yanda, and Ngana 2010); and ENSO-induced frost (Waddell 1975). Moreover, perturbations associated with climate-change has also emerged as a burgeoning field of interest, especially in the Pacific Islands and the Arctic (Hiwasaki, Luna, and Marçal 2015; Gyampoh et al. 2009; King, Goff, and Skipper 2007; Couzin 2007). Drawing on this place-based knowledge 'hazardscapes' have been developed where the frequency, impact, and warning signs are documented through participatory techniques (Cronin et al. 2004) as well as hazard mapping (Tran et al. 2009; Cadag and Gaillard 2012) to identify vulnerable communities. Documenting and understanding local knowledge also can have the possible benefit of uncovering how disasters are conceptualized in local terms. Societies have varying concepts of risk and uncertainty that must be understood in order for outside interventions to be effective (Ellen 2007).

Local knowledge that is built up by closely observing and monitoring environmental conditions enables some indigenous people not only to respond to but also anticipate perturbations such as tsunamis (Lauer 2012), cyclones (Paul and Routray 2013), or heavy rains (Roncoli, Ingram, and Kirshen 2002). In many cases responses to hazards are graded with 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). Moreover, knowledge of wild or semi-domesticated plants also become survival foods in times of resource shortage (Yates and Anderson-Berry 2004).

Scholars also make the important point to avoid romanticizing IEK (Dekens 2007; Kelman, Mercer, and Gaillard 2012; Redford 1990). Local knowledge and practices has the potential to lead to resource depletion, insufficient building practices, or unequal resource distribution that renders those societies more vulnerable to disaster not less (Diamond 2005). In other cases there may not be knowledge of previous disturbances because they are infrequent and the intergenerational links have been severed by colonialism (King, Goff, and Skipper 2007) or due to migration, people may not have built up detailed placed-based knowledge (Nunn et al. 2007).

Recently, scholars have argued that the integration of IEK with western scientific knowledge is the most effective pathway towards reducing disaster risk and vulnerability (Mercer et al. 2010; Mason et al. 2012; Gaillard and Mercer 2013; Gadgil, Berkes, and Folke 1993; Mercer et al. 2012). A number of frameworks have been proposed that involve participatory techniques (Hiwasaki et al. 2014; Mercer et al. 2008) to co-generate knowledge (Schuttenberg and Guth 2015; Rathwell, Armitage, and Berkes 2015). Yet integration and participation continue to by hampered assumptions that indigenous knowledge is static, ancient wisdom that can be seamlessly cataloged and inserted into western science frameworks (Lauer 2017). Likewise local knowledge systems may be grounded in different ontologies that are not necessarily commensurable with western science (Latour 1993).

Importantly, it is becoming increasing apparently that utilizing IEK in disaster management or prevention is inherently a political processes (Oliver-Smith 2002; Hoffman and Oliver-Smith 2002). Although the rise of IEK-focused disaster research may lead to local empowerment, it has a mixed record and may instead disempower community actors and increase centralized control (Cooke and Kothari 2001). Rather than supporting local knowledge, these techniques can displace it with western expert knowledge and techno-scientific solutions implemented by state actors (Gunewardena and Schuller 2008). As climate change increases the intensity and frequency of environmental perturbations, policy makers, researchers, and disaster experts must be reflexive about their own assumptions and provide a space for local people to define and control their own knowledge autonomy (Turnbull 2009).

Google search criteria:

((“hazards” OR “disaster” OR “tsunami” OR “cyclone” OR “eruption” OR “hurricane” OR “flood” OR “fire” OR “storm” OR “wind”) AND (“holistic knowledge” OR “indigenous knowledge” OR “traditional knowledge” OR “local knowledge” OR “indigenous practices”))

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3. Available ILK on sediment retention, erosion control, soil formation

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Ethnopedology is a field of study that focuses on IPLCs soil and land knowledge systems, management systems and beliefs (Peña-Venegas et al 2016). Most of the ethnopedological studies have been conducted in fragile agro-ecological zones with focus on local soil classification, effective land and water management systems (Barrera-Bassols and Zinck 2003). Local farmers tend to use visually observable signs to access soil health such as presence or absence of indicator plants, growth vigor of plants, soil color, and tilth, texture, and compaction (Omari et al 2018). Local ethnopedological knowledge may reflect subtle differences in soil productivity that are overlooked by conventional soil science. Local ethnopedological frameworks define the important distinguishing characteristics of soils in terms of factors such as location, wider ecological, social and historical interactions and help local farmers make soil management decisions (Osbahr and Allan 2003). Studies on indigenous home gardens showed improvement in soil fertility (Pinho et al 2011, da Cunha Salim 2018).

Some IPLCs still use the traditional methods of erosion control such as terracing (Tiwani et al 2008), which prove to be effective and sustainable (Engdawork and Bork 2014). Purpose and effect of terracing may vary based on geology and soil properties, but most common benefits are improved water retention, slope stabilization and reduced soil erosion and surface runoff (Cots-Folch et al. 2006). Chen et al (2017) studied a variety of terraces in China such as level and bench terraces, slope-separated terraces, zig terraces fanya juu terraces and half-moon terraces with slopes ranging from 3 to 35 degrees and concluded that terraces are effective to prevent soil erosion. The key ecosystem services provided by terracing are erosion control (11.46 ± 2.34)[1], runoff reduction (2.60 ± 1.79), biomass accumulation (1.94 ± 0.59), soil water recharge (1.20 ± 0.23), nutrient enhancement (1.20 ± 0.48) and enhancement of plant seedlings survival rate, ecosystem restoration and increase in crop yields (Wei et al 2016).

However, the current trend is that terraced landscapes are being abandoned worldwide due to migration to cities (Chen et al 2017), mechanization of agriculture and the reduction of people in agriculture (Mauro 2011). Abandoned terraced landscapes increase soil erosion and risk of landslides (Tarolii et al 2014) and the loss of place-based knowledge regarding terrace construction and maintenance (Chen et al 2017).

Another wide-spread practice known as slash and burn (shifting) cultivation is more controversial. On one hand, traditional slash and burn practices with long fallow periods (20 years and more) create black carbon, which contributes to the soil organic matter (Rumpel et al 2006) and has a carbon sequestration potential (Shrestha et al 2010). Amazonian Terra Preta soils famous for their fertility were created by indigenous peoples

[1] "Quantitative studies regarding each of our selected ecosystem services (ESs) associated with terracing were based on 300 selected publications. A key indicator (δ), defined as the ratio of different ESs under terraced and non-terraced slopes, was used to quantify terracing benefits. Non-terraced slopes were considered as controls, and from this point on, they will be referred to as "slopes". A δ value of 1 (i.e., no difference between terraces and slopes) is used as the threshold to distinguish the impact of terracing. If the δ value is N1, terracing is considered to play a positive role. On the other hand, if the δ value is lower than 1, it is considered that terracing produces a negative impact" (Wei et al 2016, p. 390).

between 450 BCE and 950 and possibly through slash and char practice (Glaser et al 2001).
The formation of rich Terra preta soils (Portuguese - Dark Soil) is attributed to residues of incomplete combustion (black car-bon), derived mainly from cooking fires which correspond to the morphological and chemical contents of 'Terra Preta' soils. Studies by paleoecologists and soil specialists tend to consider that the formations of these soils have their origin in human permanent or semi-permanent settlements and the production over time of rich soils around their immediate settlements.
IPLCs emphasize that success of the slash and burn systems depend on appropriate fallow periods (Tangjang 2009). For example, after each fallow/cultivation cycle soils were observed to need longer time to recuperate (Styger et al 2007). However, on the other hand, the fallow periods have been shortening (Rumpel et al 2006) due to various socio-economic factors, which leads to soil erosion, deforestation (Palm et al 2005) and carbon emissions (Klanderud et al 2010, Palm et al 2004). Although shifting agriculture has been decreasing over last few decades, it remains widespread covering about 280 million hectares worldwide with majority in the Americas (41%) and Africa (37%) (Heinimann et al 2017). Shifting cultivation is predicted to decrease significantly in all regions over the next 20 years and almost disappear in all regions by 2090 (Heinimann et al 2017).

390 W. Wei et al. / Earth-Science Reviews 159 (2016) 388–403

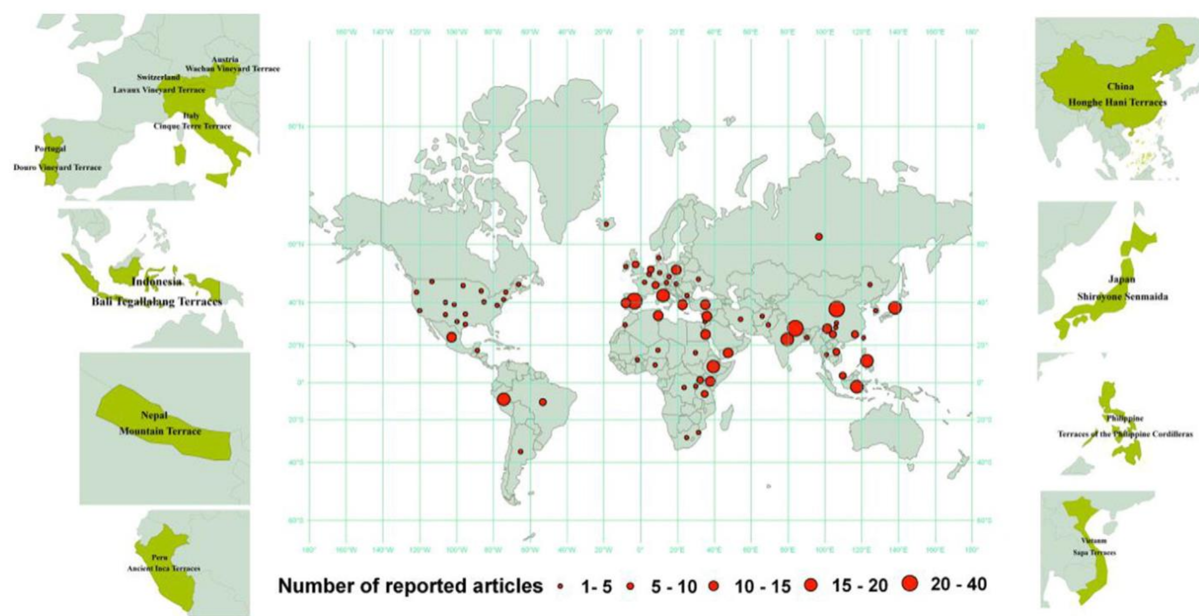

Fig. 1. Worldwide distribution of terracing. (Note: the most representative ancient terraces across the globe were especially extracted in both the left and right sides of the figure, based on the World Heritage List of UNESCO (United Nations Educational, Scientific and Cultural Organization) and GIAHS (Globally Important Agricultural Heritage Systems) as well as some other important historical terraces recorded in literature. They were used for distinguishing ancient terracing practices from modern terraces.)

PLOS | ONE   A global view of shifting cultivation

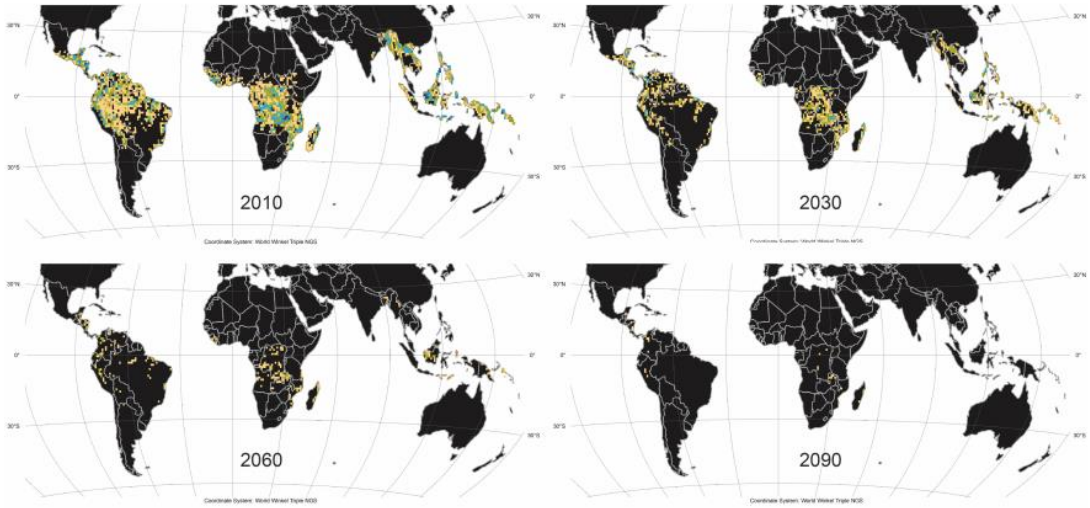

Fig 7. Preliminary estimates of changes in the occurrence of shifting cultivation between today and 2030, 2060 and 2090. This visualization is based on the estimation of landscapes showing signs of shifting cultivation around 2010 (Fig 5) as base year and estimated decreases of shifting cultivation (Table 3) based on the expert surveys and observed trend between the Butler map and our 2010. This figure was elaborated by the first author using ArcGIS 10.4.

https://doi.org/10.1371/journal.pone.0184479.g007

Heinimann et al 2017

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APPENDIX 2 – Detailed analysis of NCPs

1. NCP 1: Habitat creation and maintenance

Primary Authors: Matias Mastrangelo

1.1. IPBES Definition:

The formation and continued production, by ecosystems, of ecological conditions necessary or favorable for living beings important to humans.

1.2. Why is this NCP important?

Habitat refers to the distinct vegetation patterns and ecological communities that result from the interaction between organisms, including humans, climate (temperature and precipitation), topography (elevation, relief, topographic position), and time, normally noted as the time since a disturbance event (e.g. volcanic eruption, clearing, tilling, flooding, fire). Biome scale definitions of habitat are strongly determined by climate which changes notably with latitude, elevation. Human alteration of biome scale habitat patterns typically difficult, however human alteration of climate, and land expansion for agriculture has reached a scale where it has notable impacts on biome extent, species composition, and structure. Temperate and tropical grasslands are the two biomes most significantly altered by land clearing for food; boreal, tundra, montane, and polar biomes in contrast are facing significant changes through human alternation of global climate.

At the ecoregion scale, large topographic features such as mountain ranges, marine bodies and inland seas add their influence, and at finer scales, changes in soils and soil permeability, slope steepness and orientation, and localized disturbance events such as fires add their influence. Globally 14 terrestrial biomes are identified, with 846 ecoregions, and an even larger number of fine scale habitats for which there is no uniform database. Biome, ecoregion, vegetation alliance and increasingly higher resolution definition of habitat described by dominant vegetation patterns. For example, ecoregions are defined as “relatively large units of land or water containing a distinct assemblage of natural communities sharing a large majority of species, dynamics, and environmental conditions”. At finer scales for example, the Manual of California Vegetation for example, describes 450 vegetation types found throughout the state. Ecoregional habitats are subject to the same pressures as biomes, but also to finer scale human driven pressures that can be distinct by ecoregion. Signs of irreversible habitat change are beginning to be recorded in numerous ecoregions. For example, the culmination of nearly a decade of drought in California’s Sierra Nevada forests has led to tree mortality rates as high as 60%, some predict that this mortality will increase the risk of large-scale high intensity fires, and a permanent shift from forests to woodland or shrubland habitats.

Habitat largely determines what species exist in an area, and the types of NCPs that will be provided. NCP’s that are dependent on biome scale habitat are largely associated with biodiversity’s contribution to environmental regulation – notably climate regulation. Topical forest biomes (high temperature, high humidity, and high biodiversity) because of their tremendous net primary productivity and capacity to store carbon in aboveground biomass are critical stores of biological carbon; tundra biomes, with their high humidity and low temperatures in contrast have low decomposition rates but similarly are significant stores of carbon, in this case belowground.

At finer scales, habitat is determined by local interactions (e.g. the change in soil moisture from the valley bottom to hill stop, from a north to south facing slope orientation, or changes in soil texture and permeability. Fine scale interactions that create habitat can create fine scale changes in species traits that are the source of several NCP's – including the production of material goods, food, and medicines. A good forager for example knows to seek willow as a source of aspirin in wet habitats, mushrooms or wild asparagus tips in oak woodland habitat, and wild onions in wet meadows. Unique habitats generate unique species, and species interactions. The blind Mexican cave fish (Riddle et al. 2018), while rare and easily discounted as of little value has developed insulin resistance as an adaptation its nutrient limited habitat – diabetes, the disease that currently ranks 8th amongst the global drivers of premature mortality.

Humans have frequently intervened at local scales to change habitat seeking to increase the production of one NCP, or another. For example, Mayan populations have long cleared forest patches with slash and burn systems in support of food production (NCP 11) but have used forest regeneration as a means of maintaining soil fertility (NCP 8), and supporting wild harvest of species for food, medicine, and shelter from regenerating forests. Agroecology has long used habitat manipulation within and around agricultural fields in support of food production such as creating habitat for pollinators (diversified vegetation strips or decreasing the disturbance rates (tilling or mowing) within fields). Habitat has also been manipulated to ensure the provisioning of water related services, for example conservation of riparian forest between agricultural fields as a means of protecting freshwater systems from pollution (NCP 7).

The structure, composition (richness, diversity, and abundance), location and extent of a habitat will largely determine which NCP's are provided and at what level. The greater the change between natural, or undisturbed habitat and human modified habitat, the greater the anticipated change in NCP's provided largely driven by the loss of species and change in species composition which accompanies habitat alteration.

1.2.1. What is the big environmental issue this pertains to?

The two single largest drivers of habitat loss globally are climate change and land conversion for food. Conversion of land for cities and shelter however are also increasingly driving the loss of habitat. Current estimates suggest that nearly 40% of terrestrial habitats have been converted to crop or pasture lands for food production. Land occupancy for cities ranges between 5-8%. Climate change in contrast, will drive shifts from one habitat to another such as the case with Californian forest, or montane vegetation (Nature Citation, 2018).

1.2.2. How does this NCP play a role?

Habitat is the foundation of all other NCP's. Changes in habitat (defined by species composition, diversity, and richness) can lead to important changes in NCP delivery depending on the scale and extent of the change, as well as the NCP of interest.

1.3. (Co-) production

1.3.1. How is this NCP produced?

The interaction between organisms with the environment over time produces distinct vegetation patterns that are the basis of habitat. The nearly infinite number of possible combination of interactions produces the diversity of unique habitats currently observed globally. This myriad of potential habitats is what drives context specificity of most local patterns and the struggle of conservation biology to produce maps of conservation priorities: the finer the scale of focus, the more unique, and rare each habitat becomes – the Sofie's Choice of conservation.

Habitat can be changed unintentionally, driven by external variables (e.g. increased frequency and intensity of large storms, long-term drought, increased fire frequency), or through intentional changes (e.g. burning of forests by some native populations of North America to maintain grasslands and prey, conversion of forests to agricultural lands). These intentional changes in habitat can have the aim of increasing one or more NCP as in the case of ecosystem service-based management, or green infrastructure. Examples of intentional manipulation of habitat can be found globally and can be driven by ICLP's with a deep understanding of habitat patterns and consequences of change; or can be driven without recognition, concern, or care of the NCP changes that follow. Habitat is most often characterized by a dominant vegetation pattern, whether at the local, ecoregion, or biome scale). Changes in that vegetation pattern, including in the structure, composition, location and extent of the dominant vegetation pattern are appropriate proxies for change in this NCP.

<u>*Summary of how this NCP is produced*</u>:

- ***Direct***: Species interact with environmental variables to create a dominant vegetation patterns which defines habitat. Precipitation, temperature, soils, and topography are the primary variables which define large scale vegetation patterns. At finer scales time since disturbance, such as fire, grazing, weather event (drought, flood), or frequency of the disturbance event play important roles in producing the NCP. Finally, population dynamics including population growth, loss (immigration and emigration) of dominant species contribute to habitat creation and maintenance.
- ***Direct***: Human interventions can play a direct role in habitat creation, and increasing have been playing the dominant role in habitat creation, both indirectly through climate change which both is altering regional climates as well as frequency and intensity of weather events; and intentionally through land clearing and modification.

1.3.2. How is (co)production of this NCP measured?

Species composition and diversity define a habitat. Vegetation (plant species composition and diversity) often serve a surrogate in naming distinct habitat types (Biome: tundra, tropical forest, grassland; ecoregion: Eastern Guinean Forest, Niger Delta swamp forests, Central Indochina Dry Forests, or local: redwood forest, dehesa of Spain, or the Lyondo flood plain of Zambia (Figure 1). IPLC often have unique names for habitat which are based on changes in vegetation patterns, for example the nomenclature of the Barotse kingdom's Lyondo floodplain in Zambia is based on intimate knowledge of intermediate and fine scale habitats, their characteristic vegetation and location. The intimate knowledge of these habitats and their location guides both foraging, fishing, and agricultural practices.

The degree of change in vegetation from a habitat with little human intervention, to one of heavy human intervention is often used to describe changes in habitat quality. In other cases the capacity of a habitat to produce one or more NCP's is used to define its quality. For example, dehesa oak woodlands of Spain and Portugal would revert to forest without human intervention, grazing by black pigs maintains the woodland habitat which is valued for its food, truffle, and cork production and has become a habitat strictly defined by the interaction between natural and human driven forces. The vegetation structure, density, and species composition remain the main measurement underlying the definition of this habitat. Sustainable rangeland management is another case of intentional human intervention by ranchers whom by managing herd density, and grazing rotation frequency aim to manage their pastures so that pasture vegetation shares the characteristics native grasslands. Agroforestry systems similarly manage this objective. Toledo et al (2005) provide a classification of coffee agroforestry systems ranging from rustic systems whom structure and composition aim to resemble the structure and composition of a tropical forest to monospecific sun coffee systems which bear no resemblance to tropical forest habitat, and which thus do not provide the complementary NCP's of tropical forests.

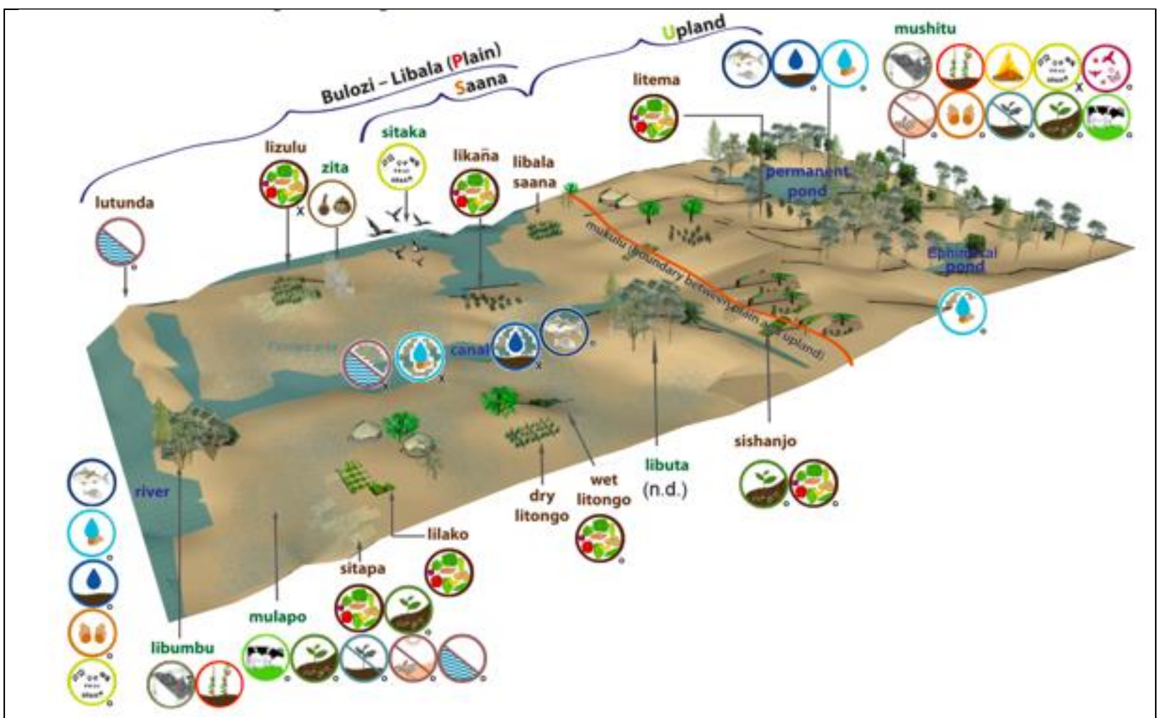

Figure 1: Habitat can be defined using ecological taxonomies, but also can be deeply rooted in local and indigenous knowledge. The Barotse classification of the Lyondo (Barotse floodplain) has both course units of habitats (river, plain, Saana, and Upland) and fine scale habitats defined (mushitu, libuta,

sisanjo etc..) which relate to distinct NCP's provided by these habitats (represented by the circular logos). The Bartose people have a clear taxonomy of the habitat and understanding the NCP's provided by these habitats. This understanding guides decision on when and where the plant, fish, or gather materials throughout the floodplain (source: Estrada Carmona et al. 201#

1.3.3. Links to other NCPS

NCP2 – pollination – Management of the pollination NCP typically requires providing habitat for pollinators (e.g. a diversity of habitat that has a diversity of asynchronously flowering plants, and located typically <1km or frequently less for solitary bees, from the target crop/plant). Low disturbance rates (tilling, plowing, weeding) also impact pollinator habitat.

NCP3 – air quality – Management of air quality

NCP4 – climate – the extent of forest biomes is a key determining factors in carbon storage. Restoration of forest habitats is essential to achieving the Paris climate targets. There are indications that this NCP may now be the single greatest value of forest habitats.

NCP5 – ocean acidification – same argument as with climate.

NCP6 – water quantity second to physical (geological, topographical, and soils based) characteristics, the amount and timing of water discharged from a watershed or basis in determined by habitat characteristics including measures of vegetation density, structure, and deciduousness/dormancy. Vegetation plays a physical role in intercepting water, increasing soil porosity and facilitating infiltration, but can also contribute to water loss through evapotranspiration. The interaction between local biotic and abiotic features/interactions determines this balance (e.g. ephemeral streams of California montane woodlands have been known to briefly resume summer water flow as native buckeyes initiate summer deciduousness). The Panama Canal Authority manages forest habitat at the basin scale in order to ensure stable water flow into the canal throughout the year without which transit by cargo ships would be impossible.

NCP7 – water quality – Vegetation density, both above (stem density), on the soil surface (litter density) and belowground (root density) slow water runoff and intercept soil particles and chemical pollution. Soil microbiome and plant further contribute by transforming, and absorbing some forms of chemical pollution, such as excess fertilizers. Large scale habitat management projects using habitat to secure water quality are well documented such as the regulation of habitat in the Hudson valley as a means of reducing water purification costs for the city of New York, of concerted efforts in the Mississippi basin to create riparian forest habitat as a means of intercepting non-point source chemical pollution driving eutrophication of the Mississippi delta.

NCP8 – soils – reducing disturbance intensity and frequency (tillage), use of cover crops, and maintaining rather than removing crop residues are all forms of managing agroecological habitat in support of soil formation.

NCP9 – hazards – Conservation of mangrove forest habitat, mussel shoals, eelgrass beds, or coral reefs are all used a means of protecting human populations from storm surges and coastal flooding. Wetland habitat can also be managed to protect urban populations from flood events as is the case with the Yolo Bypass and the city of Sacramento California.

NCP10 – pests – Management of the pest control NCP typically requires providing habitat for pest control agents (e.g. habitat that has a low disturbance frequency located typically <1km or frequently less for parasitoids and predators of insect pests). Habitat can also be used to “fragment” an agricultural landscape and reduce the movement of pest species was found with the coffee berry borer and fragmented coffee landscapes of Costa Rica. Low disturbance rates (tilling, plowing, weeding) also impact parasitoid and predator habitat.

NCP12 – food – natural habitats are typically low in food production with higher food production values obtained from largely converted natural habitat. The greater the difference between original habitat, and the resulting “agricultural” habitat, the greater the difference in NCP’s provided by the habitat in question. Conversion of tropical forests to pasture, or annual crop fields for example, largely pits food production against other NCPs; in contrast pasture systems in grassland habitats, complex agroforests in forest habitats, or rice cultivation in wetland habitats provide a greater opportunity for capturing multiple NCP’s including food.

NCP14 – medicine – Medicines are produced by species interactions, notably a prey seeking chemical protection against a predator. Aspirin for example is a chemical compound found in willows (*Salix spp.)* as protection against browsers. Habitats where interactions between predator and prey populations are high will produce a variety of medicines. Loss of habitat and biodiversity in turn drives the loss of as of yet undiscovered medicines and reduces the number of interactions which yield new medicines. One caveat is that habitat change can drive novel species interactions, which are often the source of new biochemicals.

NCP15 – learning – Unique habitats yield unique lessons to be learned whether about the uniqueness of planet earth and its habitats; understanding and learning how the combination of place, climate, time, topography drives changes in habitat patterns gives meaning to ICLP as well as to Generation Xer’s and Millennials. The unique species found in habitats, and their adaptation to the habitat in question is continuously the source of new learning, from the complex origami like folding wings of earwigs inspiring the development of nanomaterials and architectural designs, to the hydrophobic nature of some leaves being mimicked to develop graffiti proof paints or breathable waterproof clothing are all examples of learning. Finally, experiencing habitat is ultimately one of the best means of learning about one-self.

NCP16 – experiences – travel and tourism are driven by a desire to explore, experience, and in some cases, understand new habitats. Seeing and experiencing someplace new, taller, older, prettier, drier, more diverse, or just different than the last underpins motivation to travel.

NCP17 - identities – Habitat is a major contributor to identity, the simple question of “where are you from” when meeting a stranger drives a mental image of a location, and its habitat.

1.3.4. Indicators of NCP (co-) production

NCP	Production Function	Indicator/ Proxy	Rationale/ justification for why this indicator/ proxy was selected	Data set	Scale of Measu	Scale of measure - time

					re – space	
Habitat Quality	Biome scale assessment of habitat quality	Biodiversity Intactness Index	*Global assessment of Biodiversity Intactness was conducted and published by Newbold et al (2016) and draws on long-term observations from across the globe. Difficult to reproduce.*	*Newbold et al. 2016*	Biome	Change since 1800.
Habitat Extent	Ecoregion assessment of remaining habitat.	Extent of each ecoregion globally	Ecoregions are well defined globally and the degree of their current extent was evaluated by Dinerstein et al. (2016) as part of the Half Earth Project. 1800 can be used as a baseline as for BII, but it is anticipated that advances in remote sensing would be capable of automatizing this assessment in the next decade or less. There is some suggestion that less that 50% remaining habitat by ecoregion would be indicative of a critical loss of habitat and their associated NCP's.	*Dinerstein et al. 2017*	Ecoregi on	Change since 1800

1.3.5. Trends in Co-Production

1.3.5.1. General (across all units of analysis)

Two recent globally biodiversity studies individually assessed habitat quality (Newbold et al. 2016; Biodiversity Intactness Index), and habitat extent (Dinerstein et al. 2017; remaining habitat by ecoregion). Both studies are support the definition of a global and regional biodiversity boundary beyond which irreversible loss of biodiversity and the NCP's it provides should be expected. Rockstrom et al. (2009), later updated by Steffen et al (2015) suggest that of nine planetary boundaries, biosphere integrity is the most surpassed. They propose the Biosphere Integrity Index (BII) as a measure of habitat intactness stating that BII assesses change in population abundance as a result of human impacts using pre-industrial era abundance as a reference point. A score of 100% indicates abundances across all functional groups at pre-industrial levels to lower values that reflect human modification of populations of plants and animals. The score can go above 100% if human modifications to habitat lead to increases in species abundances. A score of 90% is proposed as a boundary level, but the authors recognize a large degree of uncertainly and that some NCP's may be preserved with scores as low as 30%. Newbold et al. 2016 provide a biome scale assessment of BII (Figure 2).

Dinerstein et al. (2017) provide an alternate habitat based global boundary based on E.O. Wilson's suggested Half Earth concept, which using principles of Island Biogeography suggests that 80% of biodiversity, and the NCP's it provides can be maintained if 50% of terrestrial habitats can be maintained as protected or intact. Maintaining this boundary at the biome level does not make sense since the biodiversity of Amazonian, Congolese, or Sumatran tropical forests are not exchangeable. In contrast, setting a half earth target at the ecoregion level may ensure the conservation of sufficient habitat to secure many NCP's, and biodiversity. While several novel analyses of the Half Earth concept are in development it provides a rather simple, yet elegant and policy relevant measure of the habitat NCP when applied at the ecoregional scale or finer. It is important to note that the climate NCP however requires more than 50%

tropical forest habitat to be maintained in order to reach the Paris Climate Agreement commitments.

The combined half-earth and BII analyses provide a biome scale snapshot of the habitat NCP. Using half-earth and a BII of 80% suggests that only four biomes are above either thresholds (notably tundra, Boreal forests/taiga, tropical and sub-tropical moist broadleaf forests, and mangroves); though deserts and montane grassland/shrublands are only slightly below the 80% BII target. In contrast Mediterranean habitats, temperate grasslands, and flooded grassland and savannas are well below either target. Globally, 51% of habitat remains protected or intact, though as noted above, high latitude biomes are the most intact (80-90% of their extent), and temperate and tropical systems have undergone the greatest loss, or are undergoing significant loss of habitat respectively.

Both metrics have some challenges. Because BII considers the proportion of species lost by habitat, has a tendency to underestimate loss in species rich tropical habitats while over-estimating loss in the more species poor desert biomes. Half-Earth in contrast is more easily measurable using remote sensing techniques, however interpretation of whether the habitat boundaries is half protected (a legal definition), versus half intact (a qualitative definition) must be defined. Currently 15% of habitat globally enjoys legal protection, while 51% is considered intact though unprotected.

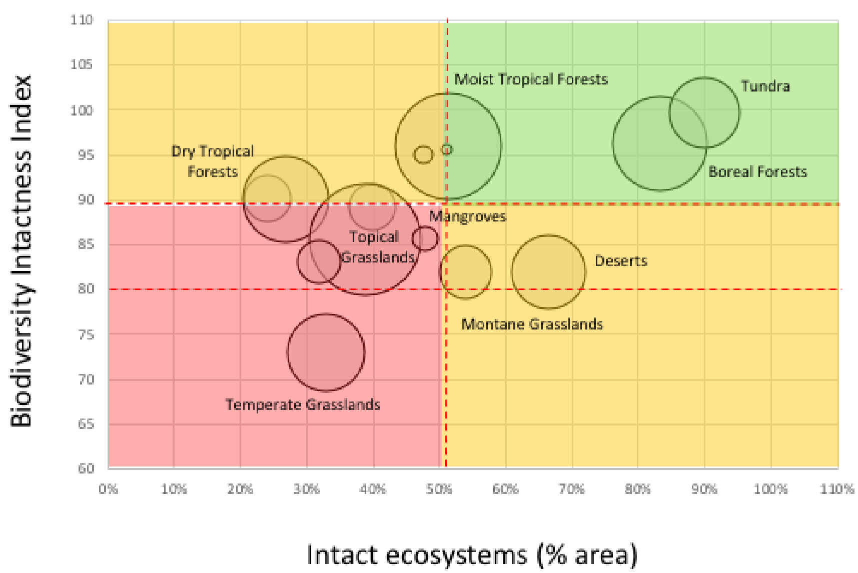

Figure 2: Assessment of two biome scale measures of habitat quality (Biodiversity Intactness Index) and habitat extent (half-earth assessment). The BII boundary for habitat quality based on species composition is indicated as 90% of the original species composition, though the degree of uncertainty regarding impact on NCP's and BII remains high and may be as low as 30%. The boundary for habitat extent is set at 50% following the Half Earth proposal required to maintain 80% of species globally. The size of the circle is indicative of the size of the biome in question (see Table 1). While both boundaries propose minimum habitat conditions required to maintain NCPs, there is no upper limit. Maintaining climate NCP requires maintaining a greater extent conservation than proposed by half earth.

Summary of NCP trends:

- ***Trend*** (& why): BII and Habitat extent are above thresholds for high latitude biomes and for moist tropical forests. Tundra and Boreal forests are the only habitats with >80% intactness. Deserts follow third with 63% intact indicating the huge habitat conservation gap between high latitude habitats and all others. High latitude habitats will come under increasing threat and loss by climate change (and possible agricultural expansion), in contrast tropical forests are at risk of loss from habitat conversion for food and fuel production.
- Biomes with the greatest degree of loss in extent are Tropical and Subtropical dry broadleaf forests (23%), temperate broadleaf and mixed forests (27% remaining), Mediterranean habitats (32% remaining) and temperate grasslands (33% remaining). These are the biomes with some of the longest exposure to post-industrial conversion of habitat to agriculture. There are indications that agricultural abandonment, particularly in the Eastern US may be contributing to a restoration of temperate broadleaf and mixed forests however.
- Tropical forests have experienced significant conversion but remain at levels of intactness at or above 50% with the exception of dry tropical forests which are below this threshold. However, tropical forest biomes are expected to continue to suffer from pressures to convert natural habitat to agricultural habitat despite their species richness and importance to the climate regulation NCP.
- ***Spatial variance*** (& why): Habitat conservation is greatest in high latitude biomes, particularly of the northern hemisphere where these biomes are extensive. Mid-latitude biomes have experienced the greatest degree of habitat loss, but are also regions where the greatest agricultural abandonment may be permitting some habitat restoration. Tropical habitats are still relatively intact but are being subjected to the greatest pressure for habitat loss.
- ***Degree of certainty*** (& why): There is a high degree of confidence associated with biome and ecoregion scale assessment of change in extent of habitat. With rapidly improving remote sensing, including LIDAR based approaches, it is anticipated that these extent-based assessments will be possible on an annual basis in the next 10-20 years. Habitat quality-based assessments such as BII have less certainty associated with them, both in terms of actual change in species composition in habitats, and of the associated change in NCP's resultant from species change. Vegetation extent and structure will most likely remain critical surrogates for regular assessments of habitat quality.

Table 1: Biome based analysis of habitat quality indicating area (km^2) of protected or intact habitat by biome, the total area of the biome (km^2), the area required to achieve half earth habitat targets (km^2), and the surplus or deficit habitat beyond the proposed boundary. The proportion (%) of the habitat that is protected or intact in indicated with biomes with greater than 50% conservation indicated in green and with those below 40% in red. Those habitats with values between 40-50% intactness are indicated in yellow. Biodiversity Intactness values derived from Newbold et al (2016) are indicated in the final column with values about the 90% value proposed by Steffen et al (2015) indicated in green, values between 80-90% indicated in yellow, and values below 70% indicated in red. It is important to note that half earth values suggest minimum boundary conditions below which biodiversity is irreversible lost. There is no upper limit to conservation targets. The discrepancy between BII and Half Earth values for desert and mountain habitats stems from the metrics, BII tends to provide greater weight to species loss in species poor habitats and under value species loss in more diverse tropical habitats.

Biome	Protected + Intact ('000 km²)	Total Area ('000 km²)	50% boundary ('000 km²)	Delta to 50% Boundary ('000 km²)	Protected & Intact (%)	Original Species BII
Tundra	7,914	8,799	4,399	3,514	90%	99.5
Boreal Forests/Taiga	12,781	15,363	7,681	5,100	83%	95.5
Tropical & Subtropical Moist Broadleaf Forests	9,979	19,458	9,729	250	51%	93.2
Mangroves	150	294	147	3	51%	92.2
Deserts & Xeric Shrublands	6,176	9,286	4,643	1,532	67%	78.3
Montane Grasslands & Shrublands	2,630	4,872	2,436	193	54%	77.1
Tropical & Subtropical Coniferous Forests	323	679	339	-16	48%	90.9
Temperate Conifer Forests	1,494	3,746	1,873	-379	40%	86.2
Tropical & Subtropical Grasslands, Savannas & Shrublands	8,236	21,271	10,635	-2,399	39%	80.5
Temperate Broadleaf & Mixed Forests	3,361	12,510	6,255	-2,893	27%	85.9
Tropical & Subtropical Dry Broadleaf Forests	927	3,854	1,927	-999	24%	86.3
Flooded Grasslands & Savannas	550	1,150	575	-24	48%	81.1
Temperate Grasslands, Savannas & Shrublands	3,349	10,197	5,098	-1,749	33%	68
Mediterranean Forests, Woodlands & Scrub	1,039	3,267	1,633	-594	32%	78.3

Source: Habitat extent values are derived from Dinerstein et al. 2017, whereas BII values are derived from Newbold et al. 2016.

1.3.5.2. By Units of Analysis

Unit of Analysis	Direction of arrow	Rationale/ justification for why you think this trend is happening
1. Tropical and subtropical dry and humid forests	Decrease	Currently 48% intact and but 90% BII for substropical coniferous forests; 51% intact and 93% BII for humid forests, but 24% intact and 86% BII for dry forests. Expected continued decline for food and energy production globally. The trend is particularly rapid in the fast growing economies of the Americas and SE Asia.
2. Temperate and boreal forests and woodlands	Temperate: Some increase Boreal: Intact, potential decrease	Temperature forests have experienced some of the greatest losses in the last century with broadleaf forests retaining only 27% of initial extent, but 85% BII; conifer forests have fared better with 40% of their extent remaining and a BII of 85%. Broadleaf forests are exhibiting some return with agricultural abandonment notably in the Eastern United States. Boreal forests are largely intact with 85% of their original extent remaining, and 95% BII. However anticipated warming in high latitudes may drive rapid changes in the coming decades.
3. Mediterranean forests, woodland, and scrub	Highly converted and declining	Mediterranean habitats only have 32% of their original extent remaining and 78% BII. These habitats are located in regions of rapid urban expansion (California, France, Italy, Spain, Northern Africa, and South Africa) and are habitat suitable to fruit and vegetable production during large parts of the year. While their total extent is rather small, Mediterranean habitats are biodiversity hotspots with unique habitats and biodiversity.

4. Tundra and high mountain habitats	Tundra: Intact and Stable or decreasing Mountain: at boundary and rapidly decreasing	Tundra habitat is the best preserved globally with 90% of the original extent intact and a BII of 99%; while not threatened by significant land use change, climate change driven habitat loss is expected to be high, including through the melting of permafrost. Mountain habitats are largely intact with 54% of original extent remaining, but only 77% BII. As with tundra habitat land use change is expected to be low, but climate change induced change is currently being observed and expected to increase even if the Paris Accord is reached.
5. Tropical and subtropical savannahs and grasslands	Low baseline and decreasing	This habitat has been subjected to the greatest conversion pressure over the past century with only 39% remaining and a BII of 80%. Continued decline is expected due to expansion of croplands and rangelands and land degradation.
6. Temperate grasslands	Low baseline, but anticipated stable.	Temperate grasslands have only 33% of their original extent remaining and a BII of 68%, the lowest recorded by Newbold et al. (2016). Temperate grasslands have the longest history of human exploitation, but it is anticipated that this expansion has halted. Urban expansion remains a real threat, though there are also significant efforts to restore these habitats with open range grazing systems.
7. Drylands and deserts	Stable	Desert habitats retain 67% of their original extent and a BII of 78%. Overgrazing and degradation remain a threat, though urbanization may reduce this threat as populations move out of low productivity rural regions. Urbanization remains a potential threat as in the Western US.
8. Wetlands – peatlands, mires, bogs	Continued loss	Wetlands have lost more than 50% of their original extent and continue to be threatened by drainage for conversion to food production. Engineering features such as levees and dikes pose and additional threat to wetland systems. In some cases however, farmers are finding management solutions which maintain the habitat contribution of wetland system (e.g. rice growers in California).
9. Urban/semi-urban	Expansion	Expected continued expansion of Urban habitat at the expense of natural habitats. There are indications however that urban grow may be accompanied by increasing efforts to include nature in urban habitats. Current estimates are the urban habitat will occupy 8-10% of the global land surface.
10. Cultivated areas (including cropping, intensive livestock, farming, etc.)	Expansion (though significant pressure to reduce or halt)	Croplands currently occupy approximately 17% of the terrestrial land surface and rangelands 23%. Some estimates suggest that this area will continue to expand and grow to meet the food security demands of a growing global population. Others however, including the CBD are calling for a significant reduction to outright halting of expansion of agricultural habitat. Several studies suggest that combinations of dietary shifts, reduced food waste and loss, sustainable intensification to close yield gaps, and trade in combination do permit feeding 10 billion with zero land expansion.
11. Cryosphere	Decreasing	Threatened by climate change and melting of permafrost.
12. Aquaculture areas	Increasing	Still largely unknown, though there is currently increasing attention being paid to terrestrial (and coastal) as well as off-shore aquaculture as a means of reducing pressure on land-based systems to produce animal meat. Even off-shore based systems may be dependent on terrestrial systems for feed production however.
13. Inland surface waters and water bodies/ freshwater	Decreasing	Degradation from overuse and abuse for irrigation, contamination, and pollution.
14. Shelf ecosystems (neritic and intertidal zone, estuaries, mangroves)	Stable to Declining	Coastal areas, particularly in temperate and tropical regions declining driven by urbanization, and to a lesser extent aquaculture.
15. Open ocean pelagic systems	Intact	Intact though threatened by pollution, particularly by plastics, and over-fishing changing community composition.
16. Deep-sea	Intact	Largely intact

17. Coastal areas intensively managed and multiply used by people	Declining	Like Shelf ecosystems, declines driven by urbanization, and to a lesser extent aquaculture.

1.4. Summary

Habitat continue to be in significant decline globally (Butchart et al. 2010). The extent of protected and intact habitat globally provided a critical indictor of NCP1. Numerous indicators of change in habitat quantity and quality exist and have been the subject of numerous review. Change in quantity is best measured as the change in the extent of suitable habitat (ESH); quality in contrast benefits from some measure of species composition with recent evaluations using the Biodiversity Intactness Index as a surrogate measure (Scholes and Biggs 2005). ESH measures the extent of suitable habitat relative to a reference year whereas BII is the compositional intactness of local communities measured as geometric mean across all species originally present of the species relative abundance in comparison to an undisturbed state. BII is assumed to capture biodiversity's functional value and contribution to NCPs (Steffen et al. 2015). A science target of 50% has been proposed for the habitat conservation (Wilson 2016; Dinerstein et al. 2017; Walter Willett et al. 2019) whereas others have proposed 90% (ranging between 30-90%) as a science target for BII (Steffen et al. 2015). ESH and BII in combination speak to status and trends of habitat quantity and quality. Both indicators combined suggest that only four biomes are above either thresholds, namely Tundra, Boreal forests/taiga, Tropical and sub-tropical moist broadleaf forests, and Mangroves (Walter Willett et al. 2019). In contrast, Mediterranean habitats, temperate grasslands, and flooded grassland and savannas are well below either target and continue to decline. Chapter 2 – Nature discuses status and trends in nature in more detail. Many biomes, particularly those at high latitude, are under increasing threat and loss by 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).

NCP1- Habitat

	Potential Nature's Contributions
Indicator	(1) Extent of Suitable Habitat (2) Biodiversity Intactness Index
Trend During the last 50 years: 2 = Major increase (>20%) 1 = Increase (5% to 20%) 0 = No change (-5% to 5%) -1 = Decrease (-20% to -5%) -2 = Major decrease (< -20%)	-2 ESH -2 BII
Spatial variance	3 ESH 3 BII
Variance across social groups	NA
Degree of certainty	ESH 4

	ESH 4

1.5. References

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2. NCP 2 - Pollination and dispersal of seeds and other propagules

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2.1. IPBES Definition:

Facilitation by animals of movement of pollen among flowers, and dispersal of seeds, larvae or spores of organisms, beneficial or harmful to humans.

2.2. Why is it important?

More than three quarters of the leading types of global food crops rely to some extent on animal pollination for yield and/or quality (Klein et al., 2007). Propagule dispersal is equally dependent on animals for propagule dispersal (Howe & Smallwood 1982). Ecosystems provide critical habitat for these pollinators and seed dispersers.

2.3. (Co-) production

2.3.1. How is it produced?

Pollination

Pollination is the transfer of pollen from the male part of the flower to the female part of the flower. This is often done by animals (see Table 2 for a detailed account of pollinator families). A diverse community of pollinators generally provides more effective and stable crop pollination than any single species (Garibaldi et al., 2013: Mallinger et al., 2015). A high diversity of pollinators is preferable because 1) this increases the probability that a pollinator able to pollinate the plant, or the most effective pollinator, will be present (Blüthgen et al., 2009), 2) different species provide stability in pollination across days with variable weather (Brittain et al., 2013a), 3) global environment, e.g. climate, is changing and diversity ensures that some pollinator will be common and produce pollination in the future (Brittain et al., 2013a; Winfree and Kremen, 2009), 4) structural differences in plants mean that different pollinators with different preferences will be more effective (Hoehn et al., 2008), 5) synergistic interactions among pollinators make cross-pollination more effective with a diverse community (Brittain et al., 2013b), 6) future crops grown in a certain region may require other pollinators than presently grown crops. To ensure that different pollinator species are present, it is important to maintain a variety of different resources, such as nesting sites and food resources (Shackelford et al., 2013). A diversity of pollinator habitat is needed to maintain a high diversity of pollinators, as different species vary in their requirements.

The vast majority of pollinator species are wild, including more than 20,000 species of bees, together with thousands of species of flies, butterflies, moths, wasps, beetles, trips, birds, bats and other vertebrates. A few species of bees are widely managed, including the western honey bee (*Apis mellifera*), the eastern honey bee (*Apis cerana*), some bumble bees (Velthuis et al., 2006), some sting-less bees, and a few solitary bees (Bohart, 1972; Hansted et al., 2014).

Both wild and managed pollinators have globally significant roles in crop pollination, although their relative contributions differ according to crop and location. In general, wild insects pollinate most crops more effectively than honey bees and pollinator diversity contributes to crop pollination even when managed species (e.g., honey bees) are present in high abundance (Garibaldi et al., 2013). Hence, crop yield and/or quality depend on both the abundance and diversity of pollinators (Kremen et al., 2002, Garibaldi et al., 2013).

Propagule Dispersal

Seed dispersal is the transfer of seeds from plant sources to deposition sites where they are likely to germinate. A high proportion of plant species rely on animals for seed dispersal (see Table 3 for a detailed account of families of seed dispersers). For example, on average, 90% of woody plant species in tropical forests bear fruits that are dispersed by animals (Howe & Smallwood 1982; Gentry 1988). Animals and plants establish a mutualistic relationship through which both interacting partners benefit. Frugivores obtain a feeding reward from the edible nutritive pulp that surround seeds. In return, animals consume fruits and regurgitate, defecate, or split seeds away from maternal plants, providing dispersal services to plants (Jordano 2014). Among vertebrates, birds and mammals are the most important groups of seed dispersers (Howe & Smallwood 1982; Howe 1986; Jordano 2014), but also reptiles (Olesen & Valido 2003; Pérez-Méndez, Jordano & Valido 2015; Pérez-Méndez *et al.* 2016), fishes (Gottsberger 1978; Howe & Smallwood 1982; Costa-Pereira & Galetti 2015) and amphibians (da Silva *et al.* 1989; Da Silva & De Britto-Pereira 2006), including tadpoles (Arribas 2015), contribute to seed dissemination. In addition, some invertebrate groups such as dung beetles (Andresen & Feer 2005) or ants (Berg 1975; Howe & Smallwood 1982) may act as important secondary seed vectors in some ecosystems.

Seed dispersal is advantageous for plants because 1) enables the movement of seeds away mother plants where seed mortality is quite high, 2) promotes the arrival of seeds to suitable sites for germination, 3) seeds benefit from gut passage which usually enhances seed germination, and 4) promotes gene flow within and among plant population (Howe & Smallwood 1982; Loveless & Hamrick 1984). The effectiveness of frugivorous animals as seed dispersers is context-dependent across a wide range of taxonomic, spatial, and temporal scales. However, functional redundancy among seed dispersers is usually low (McConkey & Brockelman 2011; Bueno *et al.* 2013; González-Castro, Calviño-Cancela & Nogales 2015). Therefore, a highly diverse community of frugivores ensures the maintenance of the full range of functional processes involved in seed dispersal. This is beneficial for plants because 1) seeds arrive to a wider variety of deposition sites as different species use the habitat differently, 2) it enables complementarity of seed dispersal services provided, 3) it increases functional redundancy, which is linked to resilience of seed dispersal systems (Hooper *et al.* 2005; García *et al.* 2013), 4) it decreases the probability that forbidden interactions occur as the result of morphological mismatches between fruit sizes and gape width of frugivores (González-Varo & Traveset 2016), and 5) it improves colonization of new habitats and post-disturbance recovery of vegetation (Howe & Smallwood 1982), and 6) improve the ability of plants to track climate shifts (Naoe *et al.* 2016; González-Varo, López-Bao & Guitián 2017).

Summary bullet list of how this NCP is produced:

- ***Direct***: Pollen is deposited on stigma by pollinator
- ***Direct***: Seeds are moved and deposited by animals
- ***Indirect***: Pollinator and seed disperser diversity increases effectiveness of pollination and seed dispersal

- ***Indirect***: Pollinator and seed disperser habitat necessary for pollinator and seed dispersal populations

2.3.1.1. Links to other NCPs

NCPs that depend on the presence and reproduction of plants, which depend on pollinator or animal-mediated seed dispersal include:

NCP 1- Habitat - Climate change is forcing plants to migrate to higher latitudes and altitudes to respond to the increasing temperatures (Chen *et al.* 2011). Assistance by animals is essential for many plants as usually they are the only vectors that transport seeds at very long distances. (Hampe 2011; Naoe *et al.* 2016; González-Varo *et al.* 2017). Seed dispersal services assisted by animals are crucial for vegetation recovering after disturbances (Cordeiro & Howe 2003). Pollination can be generally important for habitat maintainance through their role in pollinating about 87% of wild plant species (Ollerton et al., 2011).

NCP 2 - Pollination - Wild plants produces fruits and seeds important for other organisms, including seed dispersers, so pollination and seed dispersal are interconnected.

NCP 3 – Regulation of air quality- For pollination and seed dispersal, no general relation could be found. However, some big trees which can be important for air quality in cities are pollinated and dispersed by insects (Novak et al., 2006).

NCP 4 – Regulation of climate - Tropical forests store more than half of total atmospheric carbon storage (Pan *et al.* 2011). Around a 90 % of woody plant species in the tropics produce fleshy fruits (Howe & Smallwood 1982; Gentry 1988) and rely on large-vertebrate species for seed dispersal and recruitment. Large-bodied species are especially important for large seeded species, which usually have higher woody density (higher carbon storage) than small-seeded and abiotic dispersed plants (Bunker 2005). Future projections indicate that defaunation of large frugivores in tropical forests triggers a long term collapse of aboveground biomass (Bello *et al.* 2015; Peres *et al.* 2016), with losses of between 2.5-5.8 % on average, but reaching 37.8 % in some defaunated scenarios (Peres *et al.* 2016). Indirectly pollinators can play an important role here as well as around 94 % of tropical plants are animal pollinated (Ollerton et al., 2011).

NCP 6 – Regulation of freshwater quantity - Pollination and propagule dispersal by animals is a widespread phenomenon across freshwater ecosystems, including dispersal by fishes (Gottsberger 1978; Howe & Smallwood 1982; Costa-Pereira & Galetti 2015) and amphibians (da Silva *et al.* 1989; Da Silva & De Britto-Pereira 2006) among others. Relationships between pollination, propagule dispersal and freshwater quantity and quality is mostly indirect, and sometimes interact in complex ways. For example, several wasp-pollinated and animal-dispersed trees (*Ficus* sp.) in Philippines forests are the main resource of clean water for indigenous people (R. King, personal communication). These plant species filter water during the rainy season producing the most crystal-clear water in the forest. Then, during the dry season, indigenous people obtain the water by cutting the trunk or branches of Ficus trees.

NCP 7 – Regulation of water quality - Pollination and propagule dispersal by animals is a widespread phenomenon across freshwater ecosystems, including dispersal by fishes (Gottsberger 1978; Howe & Smallwood 1982; Costa-Pereira & Galetti 2015) and amphibians (da Silva *et al.* 1989; Da Silva & De Britto-Pereira 2006) among others. Relationships between pollination, propagule dispersal and freshwater quantity and quality is mostly indirect, and sometimes interact in complex ways (see NCP 6).

NCP 9 - Natural Hazard impact reduction - No relation to pollination or seed dispersal have been found.

NCP 10- Regulation of pests - There are some applications and trials where bees, especially bumblebees, have been used to transport biological pest control agents to flowers to reduce pests (Kevan et al., 2003).

NCP 11 - Energy - Pollinators and seed dispersers contribute to production of bio-fuel crops, e.g. canola and palm oil (IPBES, 2016, Ollerton et al., 2016).

NCP 12 - Food and feed - Pollinators and seed dispersers contribute to production of food and feed (IPBES, 2016, Ollerton et al., 2016). Pollinators are especially important to fruits and vegetables which supply many micronutrients to human diets (Smith et al. 2015).

NCP 13- Materials - Pollinators and seed dispersers contribute to production of fibers (e.g., cotton and linen), construction materials (timbers), musical instruments, and other material goods (IPBES, 2016, Ollerton et al., 2016).

NCP 14 – Medicines - Pollinators and seed dispersers contribute to production of plants used as medicines (IPBES, 2016, Ollerton et al., 2016).

The cultural context is critical in determining the demand for NCPs dependent on pollinators or seed dispersal so the value of pollination and seed dispersal is influenced by:

NCP 15 – Learning - Pollinators and frugivores could function as great examples for learning as they are relatively well known and consists of emblematic species. Among examples of emblematic pollinators are bumble bees, stingless bees, honey bees, hummingbirds, sunbirds or bats. Many other vertebrate species, including the charismatic megafauna (e.g. elephants), are also especially useful for learning about the importance of seed dispersers as providers of ecosystem services and their contribution to the functioning of nature.

NCP 17 - Identity

Plants that depend on pollinators or seed dispersers are important in arts and crafts, recreational activities and as sources of inspiration for art, music, literature, religion, traditions, technology and education.

2.3.2. How is it measured?

Pollination:

Pollination can be measured in various ways and there are many definitions (Inouye, 1994). The most direct way to measure the pollination event is the amount and quality of pollen deposited on the stigma (Aizen, 1997). This does not, however, capture the result in fruit or seed set, which can be another measure of pollination success (e.g. Bos et al., 2007). As a proxy for pollination, people use the number and diversity of pollinators (Garibaldi et al. 2013; Garibaldi et al. 2016). These measurements must be done locally. Habitat dominance (local and landscape complexity) can be measured globally. The abundance and diversity of pollinators may be predicted from landscape and local complexity (Batáry et al., 2011; Holzschuh et al., 2010). An index of landscape dominance (i.e. % of cover of the main habitat type) can indicate habitat diversity.

Propagule Dispersal:

The most direct measure of seed dispersal effectiveness (SDE) by animals is the number of new adult plants produced by their dispersal activities (Schupp 1993; Schupp, Jordano & Gómez 2010, 2017). Following the framework proposed by Schupp et al. (2010, 2017), this can be determined as the number of seeds dispersed by a single disperser species (quantitative component) multiplied by the probability that a dispersed seed produces a new adult individual (quality component) (i.e., SDE= Quality x Quantity). These two components are decomposed in several subcomponents. Quantity is determined as the product of *i*) the number of visits by a single species and *ii*) the number of removed seeds per visit. Quality, in turn, results from the multiplication of *i*) the probability that a seed remains viable after handling by dispersers (e.g. gut treatment) and *ii*) the probability that a seed survives, germinates and establishes as a new adult in a given deposition site. These measures can be obtained at species (McConkey *et al.* 2015) or community (González-Castro *et al.* 2015) level but are always local measures.

Local richness and abundance of seed dispersers correlates positively with seed dispersal function (Garcia & Martinez 2012). At large spatial scales, diversity of seed disperser animals and seed dispersal function (visitation rate and/or seed removal) correlates with habitat degradation (i.e., modification of habitat quality) and habitat fragmentation, respectively (Fontúrbel *et al.* 2015). A good proxy of the dispersal function may be, therefore, the proportion of landscape dominated by continuous forests (e.g. > 600 ha) in a given area (Markl *et al.* 2012).

2.3.2.1. Indicators of NCP (co-) production

NCP	Production Function	Indicator/ Proxy	Rationale/ justification for why this indicator/ proxy was selected	Data set	Scale of Measure – space	Scale of measure - time
Pollination	Pollinator habitat	Landscape dominance of habitat	There is strong evidence that landscape diversity is related to pollinator diversity (Potts et al., 2010, IPBES, 2016)	http://www.earthstat.org/ *Ramankutty, et al., 2008*	Global at 5 arc minutes	1 time point - year 2000

Pollination	Honey bee pollinator availability	Number of managed bee hives	*The number of beehives per area will correlate in general with the number of foraging bees available in that area. It is relatively easy to measure.*	*http://www.fao.org/faostat/en/#data/QA* *FAOSTAT, 2017*	Country and global	Annually; 1961-2014
Propagule dispersal	Seed disperser habitat	Biodiversity Habitat Index	There is evidence of a negative correlation between habitat loss, degradation and fragmentation and seed dispersal function (seed disperser diversity and interaction rate)	GEO BON – CSIRO (Markl *et al.* 2012; Fontúrbel *et al.* 2015)	1 km^2 resolution	Annually Available period: 2000-Present day

2.3.3. Trends in Co-Production

2.3.3.1. General (across all units of analysis)

Pollination:

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. 2016a, 2016b). There are very few historical records around the world for the pollination process itself (IPBES 2016, Potts et al. 2016a, 2016b). More information, although still scattered, is available on the diversity of pollinator species (IPBES 2016, Potts et al. 2016a, 2016b), which can be employed as a proxy for the mean and stability of pollination (Garibaldi et al. 2013, 2015, 2016). The Red List assessments by the International Union for Conservation of Nature (IUCN) indicate that 16.5 per cent of vertebrate pollinators are threatened with global extinction (increasing to 30 per cent for island species) (IPBES 2016, Potts et al. 2016a, 2016b). Declines in bee diversity over the last century have been recorded in industrialized regions of the world, particularly northwestern Europe and eastern North America (Biesmeijer et al. 2006, Cameron et al. 2011, Bartomeus et al. 2013, Carvalheiro et al. 2013, Koh et al. 2016). In contrast, a lack of wild pollinator data (species identity, distribution, occurrence, and abundance) for Latin America, Africa and Asia limit any general conclusions on regional status and trends (IPBES 2016, Potts et al. 2016a, 2016b). Furthermore, while smallholdings contribute 16% of global farmland area and 83% of the global agricultural population (and occur mostly in developing countries), only 22 of 190 crop pollination and biological control studies (12%) came from smallholder-farmed landscapes (Steward et al. 2014).

Evidence on the drivers of pollinator loss, however, indirectly suggest a decline in pollinator diversity in Latin America, Africa and Asia. In particular, it has been shown that agricultural expansion and conventional intensification, which have been highly relevant in these continents during the past decades, decrease both pollinator diversity and pollination (Garibaldi et al. 2011, Potts et al. 2016b). Also, there is evidence that climate change and biological invasions, two processes affecting most regions of the world, are also main drivers of pollinator diversity loss, and also greater virulence from varroa and other pathogens (Potts et al. 2016b). Therefore, based on current knowledge, and taking into account that few exceptions may exist, declines in pollinator diversity are expected all over the world, with likely negative consequences for the mean and stability of pollination of crop and wild plants.

There are different effects of habitat disturbance on pollinator biodiversity or abundance depending on taxonomic group, type of disturbance and type of ecosystem (Montero-Castaño & Vilà 2012; Andersson et al., 2013). For example, disturbing forests can negatively affect pollinator abundance but less so richness, while disturbing grasslands can negatively affect pollinator richness but less so abundance (Montero-Castaño & Vilà 2012).

Propagule Dispersal:

Triggered by the expansion of anthropogenic activities, animal-plant interactions, including seed dispersal mutualisms, are in decline globally. Assessing global trends of animal-mediated seed dispersal directly is, however, challenging as available information is scarce, local, and geographically-biased towards tropical forests. Instead, diversity of seed-dispersers has been used as a proxy of seed dispersal functioning. A recent review (Aslan *et al.* 2013) shows that, according to the IUCN red list, 25.9 % of vertebrate seed dispersers are globally threatened. The decline is even more acute on islands, where at least 40.2 % vertebrate seed dispersers are included in a threatened category of the red list (Aslan *et al.* 2013). It is worth noting that both local extinctions and local declines in abundance are not captured with this approach. However, low abundances of seed dispersers may trigger the disruption of ecological services long before the extinction of species occurs (McConkey & Drake 2006; Dirzo *et al.* 2014; Young *et al.* 2016). Most recent data show a mean decline of 39 % and 76 % of individuals of vertebrate species in terrestrial and freshwater ecosystems in the last forty years (McLellan *et al.* 2014; Young *et al.* 2016). Therefore, the magnitude of the seed dispersal vanishing is expected to be much higher than reported.

Extinction risk hotspots for vertebrates are located in tropical regions such as Southeast Asia, South America and central Africa, while temperate regions seems to suffer a lower level of risk (Jenkins, Pimm & Joppa 2013; Dirzo *et al.* 2014; Young *et al.* 2016). Overexploitation for obtaining bushmeat, wildlife trading, and habitat loss are among the most pervasive threats behind the decline of vertebrates in these regions (Young *et al.* 2016). In addition, climate change is expected to be a major driver of vertebrates loss in the next decades (Thomas *et al.* 2004).

Extinction of vertebrates, including seed dispersers, is not a taxonomically random process, but disproportionally affects large-bodied species (Cardillo 2003). Large seed dispersers provide pivotal dispersal services as they remove a large proportion of fruits (and seeds), consume a wide range of fruit and seed sizes, and disperse seeds over long distances (Jordano *et al.* 2007; González-Varo, López-Bao & Guitián 2013; Vidal, Pires & Guimarães 2013; Pérez-Méndez *et al.* 2016). Therefore, many altered ecosystems that retain only small- and medium-sized species are losing important ecosystem services previously assisted by vanishing large vertebrates.

	Output of the joint production	**Potential Nature's Contributions**
Indicator	**Abundance of managed and wild pollinators**	**Pollinator diversity**
Trend During the last 50 years: 2 = Major increase (>20%) 1 = Increase (5% to 20%) 0 = No change (-5% to 5%) -1 = Decrease (-20% to -5%)	**- 1**	**- 2**

-2 = Major decrease (< -20%)		
Spatial variance 3 = opposite trends in different regions 2 = same directional trends in different regions but of contrasting magnitude 1 = similar trends all over the world	**3**	**1**
Degree of certainty 4 = **Well established**: Robust quantity and quality of evidence & High level of agreement 3 = **Established but incomplete**: Low quantity and quality of evidence & High level of agreement 2 = **Unresolved**: Robust quantity and quality of evidence & Low level of agreement 1 = **Inconclusive**: Low quantity and quality of evidence & Low level of agreement	**3**	**4**
Two to five most important papers supporting the reported trend	Potts SG, Imperatriz-Fonseca V, Ngo HT, Aizen MA, Biesmeijer JC, Breeze TD, Dicks LV, Garibaldi LA, Hill R, Settele J & Vanbergen AJ (2016) Safeguarding pollinators and their values to human well-being. Nature 540:220-229. Potts SG, Imperatriz-Fonseca VL, Ngo HT, Biesmeijer JC, Breeze TD, Dicks LV, Garibaldi LA, et al. (eds.) (2016) IPBES: Summary for policymakers of the assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production. 36 p, Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany. ISBN 978-92-807-3568-0.	Potts SG, Imperatriz-Fonseca V, Ngo HT, Aizen MA, Biesmeijer JC, Breeze TD, Dicks LV, Garibaldi LA, Hill R, Settele J & Vanbergen AJ (2016) Safeguarding pollinators and their values to human well-being. Nature 540:220-229. Potts SG, Imperatriz-Fonseca VL, Ngo HT, Biesmeijer JC, Breeze TD, Dicks LV, Garibaldi LA, et al. (eds.) (2016) IPBES: Summary for policymakers of the assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production. 36 p, Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany. ISBN 978-92-807-3568-0.

2.3.3.2. (co-) production UoA Summary Table

Unit of Analysis	Direction of arrow	Rationale/ justification for why you think this trend is happening

1. Tropical and subtropical dry and humid forests LUC: Deforestation	Down Down Down	LUC: Lack of data but indirect evidence of decline in pollinators (Garibaldi et al., 2011; Winfree et al., 2009). LUC: Seed dispersers: decline and extinction of vertebrate seed dispersers, especially large-bodied species. Data is scarce but biased towards tropical and subtropical forests (Markl et al. 2012; Aslan et al. 2013) Management: Extirpation of large frugivorous vertebrates for trading or bushmeat reduces seed dispersal (Redford 1992; Terborgh et al. 2008; Dirzo et al. 2014; Young et al. 2016).
2. Temperate and boreal forests and woodlands LUC: Deforestation	Down Down	LUC: habitat loss = less pollination. More data for temperate regions (IPBES 2016, Potts et al. 2016a, 2016b). LUC: habitat loss and fragmentation = reduced seed dispersal (e.g. Santos & Tellería 1994; Santos, Telleria & Virgos 1999; González-Varo 2010).
3. Mediterranean forests, woodland, and scrub LUC: Deforestation LUC: Woody encroachment	Down Down Down	Deforestation = habitat loss = less pollination (Garibaldi et al., 2011; Winfree et al., 2009). Management: intensive grazing practices = less habitat = less pollination (Garibaldi et al., 2011; Winfree et al., 2009). LUC: Deforestation = less habitat = less seed dispersal
5. Tropical and subtropical savannahs and grasslands LUC: Conversion to cropland LUC: Afforestation	Down Down	LUC: Seed dispersers: decline and extinction of vertebrate seed dispersers, especially large-bodied species. Data is scarce but biased towards tropical and subtropical forests (Markl et al. 2012; Aslan et al. 2013) Management: Extirpation of large frugivorous vertebrates for trading or bushmeat reduces seed dispersal (Redford 1992; Terborgh et al. 2008; Dirzo et al. 2014; Young et al. 2016).
6. Temperate grasslands LUC: Conversion to cropland LUC: Afforestation	Down	LUC: loss in animal-pollinated plants (Wesche et al., 2012) = less pollinators = less pollination
8. Wetlands – peatlands, mires, bogs LUC: Draining LUC: Overfishing	Down Down Down	LUC: Draining = habitat loss = less frugivores = less seed dispersal LUC: overfishing = less seed dispersal LUC: Extreme droughts = reduction fish/amphibians populations = less seed dispersal
9. Urban/semi-urban LUC: Urban expansion	Down	LUC: More urban = less plants = less pollination

Management: urban green space	Up	Management: urban green space can benefit pollinators (Hernandez et al., 2009).
10. Cultivated areas (including cropping, intensive livestock, farming, etc.)	Down Down Down	LUC: Conversion from grassland: Natural and semi-natural habitats are important both for pollination in agriculture and otherwise (Carvalheiro et al., 2010; Garibaldi et al., 2011). LUC: Conversion from forest = less habitat = less pollinators Management: intensive agriculture = pesticides and other intensive management practices = less pollinators (Garibaldi et al., 2011; Potts et al., 2010; Wood & Goulson 2017). Management: Gardens can also have a positive effect on pollination in otherwise homogeneous agricultural landscapes (Samnegård et al., 2011).
13. Inland surface waters and water bodies/ freshwater	Down Down Down Down Down Down	LUC: Channelization = less habitat = less freshwater fauna = less propagule dispersal LUC: Draining = habitat loss = less frugivores = less seed dispersal LUC: overfishing = less seed dispersal LUC: Extreme droughts = reduction fish/amphibians populations = less seed dispersal LUC: Dams and impoundments = decline of migratory fishes = less seed dispersal (especially, long distance-dispersal) Management: More pollution = less freshwater fauna = less propagule dispersal

2.4. Impacts on good quality of life

2.4.1. Different types of value

2.4.1.1. How does it contribute to good quality of life?

Many plant species that contribute to good quality of life for people depend at least in part on animal pollination and seed dispersal. Pollinators and seed dispersers are a source of multiple contributions to good quality of life including provision of energy (biofuel crops), food and feed, material (fibers, timber), arts and crafts, recreational activities and as sources of inspiration for art, music, literature, religion, traditions, technology and education (IPBES, 2016, Ollerton et al., 2016). Sales of plants dependent on pollinators and seed dispersers generate income and livelihoods. Collection of wild plants dependent on pollinators and seed dispersers are important in subsistence and for recreation and cultural values. Honey collected from bees is also an important product in many areas.

According to IPBES framework, there are several types of values to which pollinators and seed dispersers can contribute: holistic, biophysical, health, economic, and sociocultural (Pascual et al., 2017).

Health (Nutrition: pollinated or animal-seed-dispersed cultivated or wild plants)

Pollinator-dependent food products are important contributors to healthy human diets and nutrition. Pollinator-dependent species encompass many fruit, vegetable, seed, nut and oil crops, which supply major proportions of micro-nutrients, vitamins and minerals in the human diet (Smith et al., 2015; Ellis et al., 2015). Therefore, pollination can yield direct benefits in form of food to rural livelihoods that derive both their food and income from their farms (Ashworth et al., 2009; IPBES, 2016; Hanley et al., 2015). This can be of particular importance for low-income families that lack access to marketed food, and where animal pollinated crops contribute to large part of their vitamin supply (Abrol, 2012). In addition, animal seed dispersers, by influencing regeneration patterns, are extremely important shaping the distribution and abundance of fleshy-fruited plants, which have been, since prehistorical times, a key nutritious resource for people (e.g. Roosevelt *et al.* 1996).

Economic (pollinated and seed dispersed crops)

The importance of animal pollination varies substantially among crops, and therefore among regional crop economies. Many of the world's most important cash crops benefit from animal pollination in terms of yield and/or quality and are leading export products in developing countries (e.g., coffee and cocoa) and developed countries (e.g., almonds), providing employment and income for millions of people (Klein et al., 2007; Breeze et al., 2016). Many important crops with high economic value depend of seed dispersers for natural regeneration. For example, Brazil nut (*Bertholletia excelsa*) or the açai palm (*Euterpes oleracea*), which represents a multimillion-dollar business, depend of vertebrate frugivores for seed dispersal (MEA 2005).

Economic (pollinated or animal-seed-dispersed wild plants)

Pollination and seed dispersal by animals are two key processes determining fruit production of a high proportion of wild plants. Even today, a myriad of fruit plants are harvested from forests for self-consumption or for trade worldwide, especially in developing countries (e.g. Vasquez & Gentry 1989; Gómez-Pompa & Kaus 1990). Thus, they contribute substantially to the economic development of rural livelihoods. In addition, seed dispersal, by promoting natural regeneration of vegetation, directly contributes to the production of timber, natural fibers and biofuels, all of them with an important economic value (e.g. Jansen & Zuidema 2001).

Economic (honey)

Beekeeping provides an important source of income for many rural livelihoods. The western honey bee is the most widespread managed pollinator in the world, and globally there are about 83.5 million hives producing an estimated 1.6 million tonnes of honey annually (FAO, 2016).

Economic (Income from cultural appreciation of pollinated or animal-seed-dispersed plants)

Ecotourism, the environmentally responsible travel to natural places in order to enjoy and appreciate nature (Ceballos-Lascuráin 1996), is highly motivated by the possibility of watching iconic vertebrates (e.g. large seed dispersers). It promotes the creation of employment for local people (naturalist guides, tourist accommodation, etc.). It may be used also as an educational tool by facilitating the cultural interchange between hosts and guests or by increasing awareness of local people about the benefits of nature conservation. Ecotourism may improve well-being of local people if it promotes the creation of new infrastructure and services associated to the sector. In turn, visitors are rewarded with enjoying nature and usually non-polluted environment and new traditions and cultures. Furthermore, as many wild plant species depend on pollination (Ollerton et al., 2011) it can be crucial for maintaining species rich habitats important to increase recreational value for people (IPBES, 2016).

Biophysical

Carbon storage

Carbon storage is one of the most recognized ecosystem services provided by nature. Tropical forests in particular store more than half of total atmospheric carbon storage (Pan et al. 2011). Around a 90 % of woody plant species in the tropics are dispersed by animals. Thus, preservation of frugivore communities is essential to promote the regeneration of forests and maintain their capacity for storing atmospheric carbon. Future projections indicate that defaunation of large frugivores in tropical forests triggers a long-term collapse of aboveground biomass (Bello et al. 2015; Peres et al. 2016), with losses of between 2.5-5.8 % on average, but reaching 37.8 % in some defaunated scenarios (Peres et al. 2016).

Post-disturbance habitat recovery

Habitat loss associated to anthropogenic activities is occurring at unprecedented rates, with severe impacts on biodiversity worldwide (Fahrig 2003). Seed dispersal services assisted by animals are crucial for vegetation recovering after disturbances (Cordeiro & Howe 2003). Different seed dispersers are often functionally complementary, contributing differently to vegetation regeneration. While small species contribute mostly to local regeneration, large-sized seed dispersers are essential for plant colonization, by mediating the arrival of seeds from often remote sources (Jordano et al. 2007).

Dealing with climate change

Ongoing climate change are forcing plants to moving to higher latitudes and elevations worldwide in response to shifts in temperatures to which they are adapted (Chen et al. 2011). Assistance by animals, especially large-bodied animals, is essential for many plant species to keep pace with climate change, as very often they are the only vectors providing the estimated latitudinal and altitudinal displacements needed to track their suitable climatic range (Hampe 2011; Naoe et al. 2016; González-Varo et al. 2017).

Sociocultural (direct appreciate of pollinators and frugivores, as well as of pollinated and animal-seed-dispersed plants)

Pollinators serve as important spiritual symbols in many cultures. Sacred passages about bees in all the worlds' major religions highlight their significance to human societies over millennia. A good quality of life for many people relies on ongoing roles of pollinators in globally significant heritage, as symbols of identity, as aesthetically significant landscapes and animals, in social relations, for education and recreation and in governance interactions. Pollinators and pollination are critical to the implementation of the Convention for the Safeguarding of the Intangible Cultural Heritage; the Convention Concerning the Protection of the World Cultural and Natural Heritage; and the Globally Important Agricultural Heritage Systems Initiative (IPBES, 2016). Similarly, charismatic vertebrate fauna, which often are important frugivorous species (e.g. elephants, bears, toucans, etc), are commonly used as source of inspiration and they are also important elements of many cultural iconographies (Morphy 1989). Therefore, seed dispersers are key elements contributing directly to the sociocultural and economic development of people.

2.4.1.2. How do we measure contribution?

The contribution of pollination and seed dispersal to good quality of life can be measured in several ways. For commercial commodities (e.g., honey, agricultural food, feed, and fiber crops), the price of the commodity can be one measure of value of the production, in this case per unit of output. For example, the value of habitat for pollinators in coffee production was evaluated by measuring the increase in quantity or quality of production for coffee grown in close proximity to natural forest habitat multiplied by the price of a unit of production (Ricketts et al. 2004). However, this alone does not account for the importance or value of the output, and ecosystem services alone can also be inadequate as an argument to protect species diversity and safeguard services in the future (Kleijn et al., 2015). The importance of pollination and seed dispersal can also be measured by direct contribution to good quality of life, for example through the contribution to health from improved nutrition and the production of energy, food, feed, fiber, materials, and medicines. Measuring the contribution of pollinators and seed dispersal to learning, experience, and identity is perhaps the most challenging but useful measures of contribution can be gained through use of detailed surveys of user groups.

<u>Health</u>

The health benefits can be measured by calculating the contribution to for instance the increase in yield of nutrient rich crops (Smith et al., 2015; Ellis et al., 2015). These crops then need to be used by people to attain the health benefits. Therefore, to measure the actual health benefits is complicated and depends on food usage.

<u>Economic</u>

Given that pollinator-dependent crops rely on animal pollination to varying degrees, it is estimated that 5-8 per cent of current global crop production, with an annual market value of $235 billion-$577 billion (in 2015, United States dollars) worldwide, is directly attributable to animal pollination (Potts et al., 2016). Increasing the surface of natural and/or seminatural areas within farms to preserve biodiversity of pollinators may decrease the economic profits at the short term, as the cultivated area decrease. However, at the long term it can increase the benefits because it promotes a more stable and stronger ecosystem services such as pollination and pest control (Garibaldi et al. 2017). Many important crops with high economic value depend of seed dispersers for natural regeneration. For example, Brazil nut (*Bertholletia excelsa*) or the açai palm (*Euterpes oleracea*), which represents a multimillion-dollar business, depend of vertebrate frugivores for seed dispersal (MEA 2005). In addition, seed dispersal, by promoting natural regeneration of vegetation, directly contributes to the production of timber, natural fibers and biofuels, all of them with an important economic value.

Socio-cultural (Learning, experience, and identity)

Not only honeybees but other pollinators, as well as seed dispersers have an important cultural role in many societies. Furthermore, there are fruits, vegetables and other plants that may play an important role in accepted and traditional food and other materials made from animal pollinated and/or dispersed plants. The emblematic wild pollinator/dispersers animals, (e.g. bumblebees, hummingbirds, toucans, elephants, etc.) can function as a good way of explaining and showing ecosystem functions (e.g. pollination and seed dispersal) and importance of nature.

2.4.1.3. Substitutability

Substitute for final NCP

Diet changes, or substitute products for energy, materials, medicines could affect which plants are cultivated and thereby the need for particular pollinator or seed dispersal species.

Substitute for NCP function

Honeybees have limited substitutability for the decline of wild bees. Wild insects pollinate most crops more effectively than honey bees and pollinator diversity contributes to crop pollination even when managed species (e.g., honey bees) are present in high abundance (Garibaldi et al., 2013).

In some local areas today human hand pollination is used as few wild pollinators have persisted nor is it possible or desirable by beekeepers to supply honeybee hives (Partap et al., 2001). This only works where there is a sufficiently large workforce and low wages to make it economically achievable. That is not achievable for most crop growers and can even be difficult for many crops. In general, it seems difficult to be independent of pollination services if we want to achieve food security and a good quality of life.

Substitutability of animal-mediated dispersal is challenging given wide variation in dispersal effectiveness of seed dispersers (Schupp *et al.* 2017) and low functional redundancy among seed dispersers (McConkey & Brockelman 2011; Bueno *et al.* 2013).

2.4.1.4. Indicators by value

Value type	**Indicator/ Proxy**	**Rationale/ justification for why we this indicator/ proxy was selected**	**Data set**	**Scale of Measure – space**	**Scale of measure - time**
Value type A		*There's good evidence? It's the easiest? We have the data? The data time series is long enough?*	*URL, citation*		
Health	Proportion pollinator dependent vegetables/fruit in food supply	Vegetables and fruits are important contributions to nutrition and	*http://www.fao.org/faostat/en/#data/CC* *Chaplin-Kramer et al., 2014; Klein et al., 2007; FAOSTAT database, 2017*	Country	Year; 1961-2013

		the food group which have the largest proportion of animal pollination derived crops.			
Health: Fruit provisioning		People benefits from production and consumption of wild fruits. Seed dispersers promote regeneration of fruit-bearing plants	(Vasquez & Gentry 1989; Gómez-Pompa & Kaus 1990; Moegenburg 2002, Ojiewo et al., 2015)		
Economic: Fruit trading		People benefits from trading wild fruits. Seed dispersers promote regeneration of fruit-bearing plants with commercial value	(Moegenburg 2002)		
Economic: Timber production		People benefits from timber production in natural forests. Seed dispersers promote the regeneration of trees with commercial value	(Jansen & Zuidema 2001)		
Economic value: Ecotourism	Number of visitors to National Parks in the EEUU	Number of visitors to National Parks is expected to be representative of the interest of people in nature.	*https://irma.nps.gov/Stats/*	National Park	Yearly
Biophysical	Output from pollinator dependent crops	Amount of crop production from pollinator dependent crops. Measuring crop output from pollinator dependent crops can give an estimate of the impact of pollinators on well-being. Especially if combined with vitamin and mineral contributions	*http://www.fao.org/faostat/en/#data/QC* *Klein et al., 2007; FAOSTAT database, 2017*	Country	Year; 1961-2013

		from these crops.			
Economic value: Ecotourism	Number of visitors to National Parks in the EEUU	Number of visitors to National Parks is expected to be representative of the interest of people in nature.	*https://irma.nps.gov/Stats/*	National Park	Yearly
Economic: Fruit trading		People benefits from trading wild fruits. Seed dispersers promote regeneration of fruit-bearing plants with commercial value	(Moegenburg 2002)		
Economic: Timber production		People benefits from timber production in natural forests. Seed dispersers promote the regeneration of trees with commercial value	(Jansen & Zuidema 2001)		
Biophysical: Post-*disturbance recovery of vegetation*		Seed dispersers promote recovery of disturbed forests. They enable arrival of seeds from distant sources and encourage local regeneration	(Gorchov *et al.* 1993; Wunderle 1997; Chazdon 2003; Flinn & Vellend 2005; Lamb, Erskine & Parrotta 2005; Escribano-Avila *et al.* 2014)		
Biophysical: Carbon storage		People benefit from carbon storage in natural ecosystems. Large-bodied seed dispersers promote recruitment of trees with a higher wood density	(Bello *et al.* 2015; Peres *et al.* 2016)		
Biophysical: Climate change		Seed dispersers enable plants to tracking suitable climatic ranges. Therefore it increase resilience of plants to climate change.	(Pearson & Dawson 2005; Hampe 2011; Naoe *et al.* 2016; González-Varo *et al.* 2017)		

2.4.1.5. Trends by user group

User Type	User Group	Direction of arrow	Rationale/ justification for why you think this trend is happening
Universal	Widespread and diffuse impacts	Down	*In general, associated to a decline the diversity of pollinators and seed dispersers.*
Livelihoods	Subsistence and small-scale harvesting (subsistence farming, small-scale farming, grazing, pastoralism, hunting and gathering, artisanal fishing)	Down Flat – Down	*Many wild fleshy-fruited plants rely on seed dispersers for regeneration. Decline of frugivorous animals is expected to trigger parallel declines of plants that provide fruits to food gatherers.* *There are some studies indicating that subsistence farmers depend on pollination from wild insect, somewhat more than in general, and that a decrease in abundance and diversity could affect these farmers more.*
	Commercial harvesting (farming, ranching, fishing, timber)	Flat – Down	*Commercial harvesting can be negatively affected by a decrease in ecosystem services even if they can be substituted as this increase the cost for external input.*
	Recreation and Tourism	Down	*Fauna observation is a main activity within the nature touristic sector. Many charismatic vertebrates, which are key seed dispersers (e.g. bears, toucans, iguanas, etc), are threaten with extinction across the world.*
	Energy and mining		*No specific information was found for this user type*
	Industrial, commercial, service, professional		*No specific information was found for this user type*

	Impact of Output of Joint Production on Good Quality of Life by Major Social Group	**Impact of Potential NCP on Good Quality of Life by Major Social Group (Only needed for NCP 1-10, 18; NCP 11-17 this column is the same as previous column)**
Indicator	**Health outcomes associated with decreased intake of pollinator-dependent foods** This column refers to the contribution from: (1) diverse and wild pollinators, (2) managed pollinators and other agricultural practices, (3) the capacity of humans to compensate the loss of nutrients from pollinator-dependent crops with other food sources.	**Health outcomes associated with decreased intake of pollinator-dependent foods** This column refers to the contribution from diverse and wild pollinators.
Trend During the last 50 years: 2 = Major increase (>20%) 1 = Increase (5% to 20%) 0 = No change (-5% to 5%) -1 = Decrease (-20% to -5%) -2 = Major decrease (< -20%)	**-1** Declines in animal pollinators could cause significant global health burdens from both non-communicable diseases and micronutrient deficiencies. However, these can be partially compensated by human choices of food and agricultural management.	**-2** Declines in animal pollinators could cause significant global health burdens from both non-communicable diseases and micronutrient deficiencies.
Variance across social groups 3 = opposite trends for different groups 2 = same directional trends for different groups but contrasting magnitudes 1 = similar trends for all social groups	**3** Social groups vary greatly in their capacity to compensate the loss of pollinator-dependent food with other nutritious foods. Low-income groups has less ability to compensate.	**2** Global pollinator diversity is decreasing.
Spatial variance 3 = opposite trends in different regions 2 = same directional trends in different regions but of contrasting magnitude 1 = similar trends all over the world	**3** Global pollinator diversity is decreasing but trends in managed pollinators vary widely across regions.	**2** Global pollinator diversity is decreasing.
Degree of certainty 4 = **Well established**: Robust quantity and quality of evidence & High level of agreement 3 = **Established but incomplete**: Low quantity and quality of evidence & High level of agreement 2 = **Unresolved**: Robust quantity and quality of evidence & Low level of agreement 1 = **Inconclusive**: Low quantity and quality of evidence & Low level of agreement	**2** It is unclear the degree to which humans can compensate for the loss of pollinator diversity.	**3** Despite lack of data there is a general agreement that the loss of pollinator diversity will negatively impact human health.
Two to five most important papers supporting the reported trend	Smith, M. R., Singh, G. M., Mozaffarian, D. & Myers, S. S. (2015) Effects of decreases of animal pollinators on human nutrition and global health: a modelling analysis. Lancet 386, 1964–1972	Smith, M. R., Singh, G. M., Mozaffarian, D. & Myers, S. S. (2015) Effects of decreases of animal pollinators on human nutrition and global health: a

	Potts SG, Imperatriz-Fonseca V, Ngo HT, Aizen MA, Biesmeijer JC, Breeze TD, Dicks LV, Garibaldi LA, Hill R, Settele J & Vanbergen AJ (2016) Safeguarding pollinators and their values to human well-being. Nature 540:220-229. Potts SG, Imperatriz-Fonseca VL, Ngo HT, Biesmeijer JC, Breeze TD, Dicks LV, Garibaldi LA, et al. (eds.) (2016) IPBES: Summary for policymakers of the assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production. 36 p, Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany. ISBN 978-92-807-3568-0.	modelling analysis. Lancet 386, 1964–1972 Potts SG, Imperatriz-Fonseca V, Ngo HT, Aizen MA, Biesmeijer JC, Breeze TD, Dicks LV, Garibaldi LA, Hill R, Settele J & Vanbergen AJ (2016) Safeguarding pollinators and their values to human well-being. Nature 540:220-229. Potts SG, Imperatriz-Fonseca VL, Ngo HT, Biesmeijer JC, Breeze TD, Dicks LV, Garibaldi LA, et al. (eds.) (2016) IPBES: Summary for policymakers of the assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production. 36 p, Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany. ISBN 978-92-807-3568-0.

2.5. Summary

2.5.1. Status

More than three quarters of the leading types of global food crops rely to some extent on animal pollination for yield and/or quality (Klein et al., 2007), and pollination can be a limiting factor for yields (Garibaldi et al., 2015). This is affecting both farm income but also nutrition, as many nutrient-dense foods are pollinator dependent. Pollination is also critical for subsistence farming in many parts of the world (Ashworth et al., 2009). Pollination is usually defined the transfer of pollen from the male part of the flower to the female part of the flower. This is often done by animals, including more than 20,000 species of bees, together with thousands of species of flies, butterflies, moths, wasps, beetles, trips, birds, bats and other vertebrates. Diversity of pollinators is important for several reasons. It increase the probability that an adequate pollinator is present, it provides stability over time and space and insurance of adequate pollination in environmental change, it grant an insurance in case of changes in what crops are cultivated in the future.

Being of such general importance for one of the basic organism groups in the ecosystems, plants, pollination naturally interact with many other NCPs. These includes, formation of habitats, climate regulation as around a 90 % of woody plant species in the tropics produce fleshy fruits and rely on large-vertebrate species for seed dispersal and recruitment. Pest regulation where bees can disperse biological control agents, energy crops depends at least partly on pollination by animals. Food and feed is as mentioned a large part of the pollinators contribution to people through pollination of these crops, but they also contribute to the production of fibers, construction materials, music instruments and other material goods, as wells as to production of medicines. Pollinators also contribute to cultural and social benefits such as learning about nature and ecological functioning, and as important figures in art, music and literature.

Pollination can be measured in various ways and there are many definitions but the most direct way to measure the pollination event is the amount and quality of pollen deposited on the stigma. This does not, however, capture the result in fruit or seed set, which is a common measure of pollination success . Furthermore, as a proxy for pollination, the number and diversity of pollinators have been used. These measurements must be done locally.

Agriculture has steadily become more pollinator dependent (>50% increase) during 1961-2006 (Aizen et al., 2009). However, pollinator diversity and abundance have decreased in many areas around the world (IPBES 2016; Regan et al. 2017). The Red List assessments by the International Union for Conservation of Nature (IUCN) indicate that 16.5 per cent of vertebrate pollinators are threatened with global extinction. Declines in bee diversity have been recorded in industrialized regions of the world (Biesmeijer et al. 2006, Cameron et al. 2011, Bartomeus et al. 2013, Carvalheiro et al. 2013, Koh et al. 2016). However, because of a lack of wild pollinator data (species identity, distribution, occurrence, and abundance) for Latin America, Africa and Asia it is difficult to draw any general conclusions on regional status and trends (IPBES 2016, Potts et al. 2016a, 2016b).

Though agriculture depends on pollinators, conventional intensive agricultural landscapes is contributing to pollinator decline because they generally lack habitat or have poor habitats for pollinators (Garibaldi et al., 2011; Vanbergen, 2013), they are not deliberately managed for pollination (Garibaldi et al., 2011; Potts et al., 2010; Vanbergen, 2013), and brief periods of very high pollination demand exceed supply because of extensive cultivations of mass-flowering monocultures (Rader et al., 2009). Also, there is evidence that climate change and biological invasions, two processes affecting most regions of the world, are also main drivers of pollinator diversity loss, and also greater virulence from varroa and other pathogens (Potts et al. 2016b).

Many plant species that contribute to good quality of life for people depend at least in part on animal pollination and seed dispersal. Wild plants dependent on animal dispersal of seeds are also critical to human nutrition, particularly in developing countries and for people located far from markets (Moegenburg 2002). Parallel declines of both fleshy-fruited plants and seed dispersers may create situations of food and nutrient scarcity. Reductions in seed dispersers many also contributed to declines in availability of construction materials (timber or fibers), biofuels, or medicine resources extracted from plant tissues (fruits, leaves, etc.). According to IPBES framework, there are several types of values to which pollinators and seed dispersers can contribute: holistic, biophysical, health, economic, and sociocultural (Pascual et al., 2017). Pollinator-dependent species encompass many fruit, vegetable, seed, nut and oil crops, which supply major proportions of micro-nutrients, vitamins and minerals in the human diet (Smith et al., 2015; Ellis et al., 2015). The economical value can vary between regions but many of the world's most important cash crops benefit from animal pollination in terms of yield and/or quality (e.g., coffee and cocoa, almonds), providing employment and income for millions of people (Klein et al., 2007; Breeze et al., 2016). Many important crops with high economic value depend of seed dispersers for natural regeneration. Ecotourism, the environmentally responsible travel to natural places in order to enjoy and appreciate nature (Ceballos-Lascuráin 1996), is highly motivated by the possibility of watching iconic vertebrates (e.g. large seed dispersers). Furthermore, as many wild plant species depend on pollination (Ollerton et al., 2011) it can be crucial for maintaining species rich habitats important to increase recreational value for people (IPBES, 2016).

The contribution of pollination and seed dispersal to good quality of life can be measured in several ways. For commercial commodities (e.g., honey, agricultural food, feed, and fiber crops), the price of the commodity can be one measure of value of the production. However, this alone does not account for the importance or value of the output, and ecosystem services alone can also be inadequate as an argument to protect species diversity and safeguard services in the future (Kleijn et al., 2015). The health benefits can be measured by calculating the contribution to for instance the increase in yield of nutrient rich crops (Smith et al., 2015; Ellis et al., 2015). The socio-cultural values are very difficult to measure directly and needs to be assessed more based on peoples wishes and satisfaction. However, one could estimate the availability of different plants important to different cultural traditions and how likely it is that these will decrease with pollinators declines (REF?).

Pollination is hard to substitute with something else as it is so many flowers and events that all the pollinators affect. Hand pollination will be exceedingly expensive for most farmers. Honeybees have limited substitutability for the decline of wild bees. Wild insects pollinate most crops more effectively than honey bees and pollinator diversity contributes to crop pollination even when managed species (e.g., honey bees) are present in high abundance (Garibaldi et al., 2013). Substitutability of animal-mediated dispersal is also challenging given wide variation in dispersal effectiveness of seed dispersers and low functional redundancy among seed dispersers.

Diet changes will influence the extent to which agriculture depends on insect pollinators. For instance, if current trends of increase in meat consumption and concentration of energy intake from a limited number of cereal crops continue, this would lower the pollination dependence of agriculture in the short term while further deteriorating pollinator habitats (Potts et al., 2010). However, increased demand for pollinator-dependent fruits and vegetables (Aizen et al., 2009) for both cultural and nutrient needs, will increase dependence on pollinators (Smith et al., 2015). As a large part of the problem with malnutrition is lack of nutritious food and nutrition have become more important, for example the goal 2 in UNs Sustainable Development Goals, it could be expected that countries invest more in nutrient dense food production. This could increase the need for pollinators in the future.

Seed disperser animals are also disappearing at accelerated rates in most terrestrials and freshwater ecosystems, especially on tropical and subtropical areas (Dirzo et al. 2014; Young et al. 2016). This is being mainly driven by deforestation and habitat loss, overexploitation, and climate change. Wild plants dependent on animal dispersal of seeds are also critical to human nutrition, particularly in developing countries and for people located far from markets (Moegenburg 2002). Parallel declines of both fleshy-fruited plants and seed dispersers may create situations of food and nutrient scarcity. Reductions in seed dispersers many also contributed to declines in availability of construction materials (timber or fibers), biofuels, or medicine resources extracted from plant tissues (fruits, leaves, etc.) and profits of the ecotourism sector.

2.5.2. Similarities and differences across Units of Analysis and across User Groups

There are differences between biomes for the trends in decline of pollinator diversity and abundance, pollinator deficits and agricultural dependence on pollinators. The lack of data makes it hard to make any general conclusions for large part of the world, especially in the tropics and subtropics, though indirect evidence points to declines even here. Despite the lack of information in most parts of the world, it seems that both tropical and subtropical regions are suffering a steeper negative trend in terms of seed disperser diversity and abundance than other global regions.

Some user groups have a higher dependence on pollination than others because of their direct dependence on pollinator dependent crops (Ashworth et al., 2009). Subsistence and small-scale harvesters may be particularly dependent on seed dispersers, as their diet is largely based on fruits produced by natural vegetation.

2.6. References

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2.7. Search methodology

Pollination

The following Keywords were used to set up the search strings for pollination: *Pollinator dependent, pollen limitation, pollinators, diversity, abundance, pollinator dependance*

Next the following keywords were used to represent the five value types of diverse valuation: holistic, biophysical, sociocultural, health and economic (Pascual et al., 2017): *Crop quality, crop production, pollination, crop pollination, food nutrient, food nutrition, health, decline, threat, cultural, social, tradition, indigenous, economic*

The NCP keywords were then combined with the value types keywords to form the search strings in the following way.

Holistic values

1. ((“pollinator diversity” OR “pollinator abundance” OR “pollinator diversity and abundance”) AND (“holistic value” OR “indigenous knowledge” OR “traditional knowledge”)) AND (review OR synthesis OR “meta-analysis”)

2. (“pollinator dependent” AND (“holistic value” OR “indigenous knowledge” OR “traditional knowledge”)) AND (review OR synthesis OR “meta-analysis”)

3. (pollination AND (“holistic value” OR “indigenous knowledge” OR “traditional knowledge”)) AND (review OR synthesis OR “meta-analysis”)

Biophysical values

4. (“pollinator dependent” AND (“pollination” OR “crop quality” OR “crop production”) AND “pollinator diversity”) AND (review OR synthesis OR “meta-analysis”)

5. ((“pollinator diversity” OR “pollinator abundance” OR “pollinator diversity and abundance”) AND (“pollination” OR “crop quality” OR “crop production” OR crop pollination OR “pollen limitation”)) AND (review OR synthesis OR “meta-analysis”)

6. ((“pollinator diversity” OR “pollinator abundance” OR “pollinator diversity and abundance”) AND (decline OR threat)) AND (review OR synthesis OR “meta-analysis”)

Health values

7. (pollination AND ("food nutrition" OR "food nutrient" OR health)) AND (review OR synthesis OR “meta-analysis”)

8. (“pollinator dependent” AND ("food nutrition" OR "food nutrient" OR health)) AND (review OR synthesis OR “meta-analysis”)

9. ((“pollinator diversity” OR “pollinator abundance” OR “pollinator diversity and abundance”) AND ("food nutrition" OR "food nutrient" OR health)) AND (review OR synthesis OR “meta-analysis”)

<u>Sociocultural values</u>

10. ((“pollinator diversity” OR “pollinator abundance” OR “pollinator diversity and abundance”) AND (“cultural value” OR “social value” OR “social benefit”)) AND (review OR synthesis OR “meta-analysis”)

11. (“pollinator dependent” AND (“cultural value” OR “social value” OR “social benefit”)) AND (review OR synthesis OR “meta-analysis”)

12. (pollination AND (“cultural value” OR “social value” OR “social benefit”)) AND (review OR synthesis OR “meta-analysis”)

<u>Economic values</u>

13. ((“pollinator diversity” OR “pollinator abundance” OR “pollinator diversity and abundance”) AND (profit OR “economic benefit”)) AND (review OR synthesis OR “meta-analysis”)

14. (“pollinator dependent” AND (profit OR “economic benefit”)) AND (review OR synthesis OR “meta-analysis”)

15. (pollination AND (profit OR “economic benefit”)) AND (review OR synthesis OR “meta-analysis”)

Each of these search strings gave the following number of hits in Google scholar:

1. 96
2. 36
3. 5390
4. 297
5. 2010
6. 2070
7. 19700
8. 463
9. 989
10. 73
11. 28
12. 490
13. 387
14. 143
15. 15400

Abstracts of the 15 first outputs for each string search were carefully read. Relevant literature was incorporated to the narrative review, prioritizing review and synthetic articles.

<u>Seed dispersal</u>

The following keywords were used to set up the search strings for seed dispersal: *Seed disperser, frugivore, diversity, abundance, diversity and abundance* and *seed dispersal*

Next the following keywords were used to represent the five value types of diverse valuation: holistic, biophysical, sociocultural, health and economic (Pascual et al., 2017): *Holistic* *value*, *indigenous knowledge*, *traditional knowledge, food nutrition*, *food nutrient*, *health, carbon storage*, *carbon sequestration, post-disturbance recovery, post-fire recovery, post-disturbance regeneration*, *post-fire regeneration, climate change, cultural value, social value, social benefit, profit, economic benefit.*

We then compiled the following combined search strings:

Holistic

1. ((“seed disperser” OR frugivore) AND (diversity OR abundance OR “diversity and abundance”) AND (“holistic value” OR “indigenous knowledge” OR “traditional knowledge”)) AND (review OR synthesis OR “meta-analysis”)
2. (“seed dispersal” AND (“holistic value” OR “indigenous knowledge” OR “traditional knowledge”)) AND (review OR synthesis OR “meta-analysis”)

Health values

3. ((“seed disperser” OR frugivore) AND (diversity OR abundance OR “diversity and abundance”) AND ("food nutrition" OR "food nutrient" OR health)) AND (review OR synthesis OR “meta-analysis”)
4. (“seed dispersal” AND ("food nutrition" OR "food nutrient" OR health)) AND (review OR synthesis OR “meta-analysis”)

Biophysical values

5. ((“seed disperser” OR frugivore) AND (diversity OR abundance OR “diversity and abundance”) AND ("carbon storage" OR "carbon sequestration")) AND (review OR synthesis OR “meta-analysis”)
6. (“seed dispersal” AND ("carbon storage" OR "carbon sequestration")) AND (review OR synthesis OR “meta-analysis”)
7. ((“seed disperser” OR frugivore) AND (diversity OR abundance OR “diversity and abundance”) AND ("post-disturbance recovery" OR "post-fire recovery" OR ”post-disturbance regeneration” OR “post-fire regeneration”)) AND (review OR synthesis OR “meta-analysis”)
8. (“seed dispersal” AND ("post-disturbance recovery" OR "post-fire recovery" OR ”post-disturbance regeneration” OR “post-fire regeneration”)) AND (review OR synthesis OR “meta-analysis”)
9. ((“seed disperser” OR frugivore) AND (diversity OR abundance OR “diversity and abundance”) AND ("climate change")) AND (review OR synthesis OR “meta-analysis”)
10. (“seed dispersal” AND ("climate change”)) AND (review OR synthesis OR “meta-analysis”)

Sociocultural values

11. ((“seed disperser” OR frugivore) AND (diversity OR abundance OR “diversity and abundance”) AND (“cultural value” OR “social value” OR “social benefit”)) AND (review OR synthesis OR “meta-analysis”)
12. (“seed dispersal” AND (“cultural value” OR “social value” OR “social benefit”)) AND (review OR synthesis OR “meta-analysis”)

Economic value

13. ((“seed disperser” OR frugivore) AND (diversity OR abundance OR “diversity and abundance”) AND (profit OR “economic benefit”)) AND (review OR synthesis OR “meta-analysis”)
14. (“seed dispersal” AND (profit OR “economic benefit”)) AND (review OR synthesis OR “meta-analysis”)

Each of these search strings gave the following number of hits:

1. 143
2. 1420
3. 2250
4. 19700
5. 408
6. 4580
7. 114
8. 1240
9. 2180
10. 18400
11. 86
12. 791
13. 386
14. 4260

Abstracts of the 15 first outputs for each string search were carefully read. Relevant literature was incorporated to the narrative review, prioritizing review and synthetic articles.

Table 2. Pollinators con contributing to crop and wild plant pollination.

Group	Family	Example of plant
Social bees, incl Honey bees	Apidae	Various
XX	Melittidae	Various
Mason, leafcutter bees	Megachilidae	Various
Mining bees	Andrenidae	Various
Sweat bees	Halictidae	Various
Plasterer bees	Colletidae	Various
Large Australian bees	Strenotridae	Various
Syrphid flies	Syrphidae	Various
Rodents	Muridae	Protea ssp.
Bats	Phyllostomidae	Euperua, Crescentia, Agave
Bats	Pteropodidae	Bignoniaceae, Parkia

Moths	Prodoxidae	Yucca
Moths	Lepidoptera, various	Various
Pollen wasps	Vespidae	Various
Lizards	Various	Various

Table 3. Families containing species that incorporate fruits in their diets. Note that this list underestimates the contribution of animals to seed dispersal as it does not include alternative dispersal mechanisms such as epizoochory.

Group	***Order***	***Family***
Fishes		
	Characiformes	Alestidae
		Anostomidae
		Characidae
		Citharinidae
		Hemiodontidae
		Serrasalmidae
	Cypriniformes	Anablepidae
		Cyprinidae
		Poeciilidae
	Elopiformes	
		Megalopidae
	Gymnotiformes	
		Electrophoridae
		Sternopygidae
	Lepidosireniformes	
		Protopteridae
	Osteoglossiformes	
		Mormyridae
		Osteoglossidae
	Perciformes	
		Centrarchidae
		Cichlidae
		Eleotridae
		Kuhliidae
		Nandidae
		Osphronemidae
		Terapontidae
	Polypteriformes	
		Polypteridae
	Siluriformes	

Ageneiosidae
Ariidae
Aspredinidae
Auchenipteride
Bagridae
Clariidae
Claroteidae
Doradidae
Ictaluridae
Loricaridae
Mochokidae
Pangasiidae
Pimelodidae
Schilbeidae
Siluridae

Tetraodontiformes

Tetraodontidae

Reptiles

Agamidae
Cordylidae
Corytophanidae
Dermatemydidae
Diplodactylidae
Gekkonidae
Gerrhosauridae
Iguanidae
Lacertidae
Phrynosomatidae
Platysternidae
Polychrotidae
Scincidae
Sphenodontidae
Teiidae
Testudinidae
Tropiduridae
Varanidae
Xantusiidae

Amphibians

Alytidae
Hylidae
Pelobatidae
Ranidae

Birds

Passeriformes

Acanthisittidae
Acanthizidae
Aegithinidae
Alaudidae
Artamidae
Bombycillidae
Calcariidae
Callaeatidae
Campephagidae
Cardinalidae
Chloropseidae
Cisticolidae
Cnemophilidae
Coerebidae
Colluricinclidae
Conopophagidae
Corcoracidae
Corvidae
Cotingidae
Cracticidae
Dasyornithidae
Dicaeidae
Dicruridae
Dulidae
Emberizidae
Estrilidae
Eupetidae
Eurylaimidae
Falcunculidae
Formicariidae
Fringillidae
Furnariidae
Hirundinidae
Icteridae
Irenidae
Laniidae
Malaconitidae
Maluridae
Melanocharitidae
Meliphagidae

Mimidae
Mohoidae
Monarchidae
Motacillidae
Muscicapidae
Nectariniidae
Oriolidae
Orthonychidae
Pachycephalidae
Paradisaeidae
Paridae
Parulidae
Passeridae
Petroicidae
Philipettidae
Picathartidae
Pipridae
Pittidae
Pityriaseidae
Platysteiridae
Ploceidae
Polioptilidae
Pomatostomidae
Prunellidae
Ptilonorhynchidae
Pycnonotidae
Regulidae
Remizidae
Rhabdornithidae
Rhinocryptidae
Sapayoaidae
Sittidae
Sturnidae
Sylviidae
Tephrodornithidae
Thamnophilidae
Thraupidae
Timaliidae
Troglodytidae
Turdidae
Turnagridae
Tyrannidae

Vangidae
Vireonidae
Zosteropidae

Struthioniformes

Rheidae
Casuariidae
Dromaiidae
Apterygidae

Tinamiformes

Tinamidae

Anseriformes

Anatidae
Dendrocygnidae

Galliformes

Cracidae
Megapodiidae
Numididae
Odontophoridae
Phasianidae

Pelecaniformes

Ardeidae
Threskiornithidae

Accipitriformes

Accipitridae
Cathartidae

Otidiformes

Otididae

Mesitornithiformes

Mesitornithidae

Cariamiformes

Cariamidae

Gruiformes

Gruidae
Psophiidae
Rallidae

Charadriiformes

Charadriidae
Laridae
Scolopacidae
Stercorariidae
Turnicidae

Pterocliformes

	Pteroclidae
Columbiformes	
	Columbidae
Opisthocomiformes	
	Opisthocomidae
Musophagiformes	
	Musophagidae
Cuculiformes	
	Cuculidae
Strigiformes	
	Strigidae
	Tytonidae
Caprimulgiformes	
	Steatornithidae
Apodiformes	
	Trochilidae
Coliiformes	
	Coliidae
Trogoniformes	
	Trogonidae
Coraciiformes	
	Alcedinidae
	Coraciidae
	Meropidae
	Momotidae
	Todidae
Bucerotiformes	
	Bucerotidae
	Bucorvidae
	Phoeniculidae
Piciformes	
	Bucconidae
	Capitonidae
	Indicatoridae
	Lybiidae
	Megalaimidae
	Picidae
	Ramphastidae
	Semnornithidae
Falconiformes	
	Falconidae

Psittaciformes

Cacatuidae

Psittacidae

Strigopidae

Mammals

Proboscidea

Elephantidae

Scandentia

Ptilocercidae

Tupaiidae

Primates

Callitrichidae

Cebidae

Cercopithecinae

Colobinae

Hominidae

Hylobatidae

Lemuridae

Lorisidae

Marsupialia

Didephidae

Phalangeridae

Macropodidae

Rodentia

Muridae

Sciuridae

Carnivora

Canidae

Felidae

Herpestidae

Mustelidae

Procyonidae

Ursidae

Viverridae

Chiroptera

Phyllostomidae

Pteropodidae

Perissodactyla

Equidae

Rhinocerotidae

Tapiridae

Artiodactyla

	Bovidae
	Cervidae
	Camelidae
	Moschidae
	Suidae
	Tragulidae
Ants	
	Formicidae
Dung beetles	
	Scarabeidae
Tree Wetas	
	Anostostomatidae
Bees	
	Apidae

3. NCP 3: Regulation of Air Quality

Primary Author: Pedro Brancalion

3.1. IPBES Definition:

Regulation (by impediment or facilitation) by ecosystems, of CO_2/O_2 balance, O_3 for UV-B absorption, levels of sulphur oxide, nitrogen oxides (NOx), volatile organic compounds (VOC), particulates, aerosols. Filtration, fixation, degradation or storage of pollutants that directly affect human health or infrastructure

3.2. Why is it important?

3.2.1. What is the big environmental issue this pertains to?

Air pollution is one of the major drivers of chronic diseases and premature mortality in humans, leading to 3.3 million premature deaths annually (Amann et al. 2013; Lelieveld et al. 2015). One ninth of the global deaths in 2012 were caused by air pollution, and only about a tenth of people are estimated to breath clean air (WHO 2016). Health problems associated to air pollutions are associated to major economic losses in economies worldwide (healthcare costs and reduced activity days - OECD 2016). Dust and particulate matter in the air also reduce visibility and can cause accidents, deteriorate infrastructure, and negatively impact the functioning of transport systems.

Outdoor air pollution has been a critical driver of premature mortality, especially in the most populated regions of the world (Lelieveld et al. 2015). The major human-mediated sources of air pollution driving premature mortality – industry, land traffic, residential and commercial energy use, biomass burning, power generation, and agriculture − (Lelieveld et al. 2015), are all expected to be intensified in the coming years. According to FAO, by the year 2050, urban population will increase by 2 billion people and will be concentrated in low- and middle-income countries (http://www.fao.org/3/a-i6583e.pdf), where urbanization tend to be less planned and therefore people may be more exposed to air pollution. Food production will also have to increase to supply the demand of the 9.7 billion people expected to live on Earth by 2050, which may foster the increase of cropland in 110 million hectares in developing countries (Alexandratos and Bruinsma 2012). Agricultural production methods may also have to be intensified to meet a growing demand for agricultural materials (Alexandratos and Bruinsma 2012), which may increase the use of fertilizers and machinery, which without improved application technology will increase negative impacts on air quality. Intensifying agriculture to feed the world is, however, highly debated and other solutions are being proposed (Orsini et al. 2013; Phalan et al. 2017), such as a better management of genetic resources (Jacobsen et al. 2015), new agroecological techniques (Lescourret et al. 2015) Population increase and change in dietary patterns may further increase the area of livestock production (Thornton 2010). Many gases, such as hydrogen sulfide (H_2S), and ammonia (NH_3), are emitted through ruminant fermentation, and livestock waste, which has become a serious problem with the intensive development of livestock industry (Jie et al. 2017). The expansion of agricultural lands has also fostered deforestation. Natural forest area declined ~6% from 1990 to 2015 (Keenan et al. 2015), and fires have been one of the major strategies to convert native ecosystems to agricultural lands. Consequently, global regions with higher deforestation are also those with the higher particulate matter emissions, and where the impacts of biomass burning on premature mortality linked to outdoor air pollution is higher (Lelieveld et al. 2015). Conversion of natural ecosystems and land degradation have also fostered the expansion of desertification (Geist and Lambin 2004; D'Odorico et al. 2013). Dust production has doubled over the past 100 years (Mahowald et al. 2010; Mulitza et al. 2010) and anthropogenic activities have contributed notoriously to this increase (Derbyshire 2007). Overall, emissions of SO_2 declined since 1990, but those black carbon, organic carbon, and ammonia have increased (Amann et al. 2013). European and North American emissions of ozone precursors have decreased since their peak values during the 1980s and 1990s, but have increased in many other regions (in particular Asia) (Granier et al. 2011).

3.2.2. How does this NCP play a role?

Ecosystems can store elements that can become air pollutants if they are destroyed or degraded, as when biomass is burned and natural ecosystems are converted to high-intense agriculture. The use of biofuels instead of fossil fuels may also decrease the emissions of fine particulate matter and thus contribute to air quality (Hill et al. 2009). At the same time, vegetation protect soils and can prevent dust emissions from bare lands. The sustainable management of ecosystems may thus prevent the emissions of air pollutants and consequently avoid the health and economic problems associated to air quality reduction. On the other hand, ecosystems and plants can help to reduce air pollutants concentration by trapping fine particulate matter on leaves, branches and trunks, and facilitate the activity of microbes that degrade particulates (Weyens et al. 2015), thus mitigating the health and economic problems associated to air quality deterioration. Therefore, ecosystems can help to regulate air quality and mitigate the negative impacts of pollutants on people's good quality of life. However, some materials released by ecosystems in the air, like pollen, fern spores, and fungal spores can be harmful to people and contribute to fine particulate matter and reduced air quality.

3.3. Joint production

3.3.1. How is it produced?

A. Prevention of air pollution emissions from ecosystems and fossil fuels

Ecosystems stock elements in their living and non-living components that are harmful for air quality if released in the air. When biomass is burned, like through firewood use for cooking and heating, and natural ecosystems conversion to agriculture, air pollutants like fine particulate matter, carbon monoxide, and sulfur and nitrogen oxides are released in the air and deteriorate air quality. Vegetation and litter also stabilize soils and protect them against particle detachment and transport by wind erosion (Grantz et al. 1998), a major driver of dust emissions to the air (McConnell et al. 2007; Mitchell et al. 2010; Johnson et al 2011). The use of biofuel instead of fossil fuels can also reduce the net emissions of fine particulate matter in the air and thus contribute to air quality (Hill et al. 2009).

B. Interception and deposition of air particulate matter by vegetation

Studies on dust deposition on plant canopies indicate that aboveground plant parts (i.e., leaves, bark, and other exposed parts) generally act as persistent absorbers in a polluted environment (Samal and Santra 2002; Das et al. 2006) and trees can intercept air pollutants and act as biological filters (Beckett et al. 1998). For instance, urban trees removed more than 1,000 tons of air pollutant in 1994 in Philadelphia, USA (Nowak et al. 1998), while in Chicago McPherson et al. (1994) found reductions of y 9.8 tons per day of PM_{10}. Vegetation can intercept air particulate matter and, through dry deposition (combined effect of gravity, Brownian motion, impaction and direct interception), remove these particles from the atmosphere (Beckett et al. 2000; Fowler 2002). The high roughness structure of vegetation created by leaves, branches, trunks, and litter increase the contact area with air pollutants and favor their deposition on ecosystems with higher structural complexity. Deposition may be positively correlated with hairy leaves and the wax content of the leaves, while thick leaves show lower deposition. These same attributes can be scales to ecosystem level: wind erosion is reduced with increasing ground cover, additional structural complexity (canopy layers) further reduces particle displacement, and increases particle interception. Trees with a large leaf surface area can remove 60 to 70 times more gaseous pollutants a year than small ones. (Litschke and Kuttler 2008; Salmond et al. 2016). Particulate matter may stick to plant structures or be further washed-out to soil, thus reducing the inhalation exposure of people. In addition, vegetation can serve as a barrier to the movement of soil dust fronts, thus mitigating the effects of dust storms (Engelstaedter et al. 2003).

C. Absorption of air pollutants by plants

Plant leaves absorb many different air chemical compounds that can be harmful for people, contributing to scavenge air pollutants in their organic structure (Leung et al. 2011; Salmond et al. 2016). For instance, plants can absorb atmospheric NO_2 and use it as a source of nitrogen in metabolism (Takahashi et al. 2003; Vallano et al. 2007), and absorb ozone by stomata (Taha 1996; Nowak et al. 2000). Nitrogen and sulphur gases may also be washed out to soils, transformed into other compounds, and be further absorbed by plant roots (Fowler et al. 1989; Nowak & Dwyer 2007). Some air pollutants may not be directly absorbed by plant leaves or roots. However, once they are deposited in plant parts (leaves, branches, trunks), free-living or endophytic microorganisms may help to sequester, degrade, or detoxify these compounds into non-toxic forms, which can be further absorbed by plants (Weyens et al. 2015). Once leaves fall or pollutants are washed out to soils, these processes may also be mediated by soil biodiversity.

D. Air pollution emissions from ecosystems

Ecosystems can naturally release pollutants in the air, like those resulted from natural fires (Langmann et al. 2009), pollen, fern spores, and fungal spores, that are harmful to people's health. Some of these are natural parts of ecosystem cycles, for example in Mediterranean or Australian ecosystems, can be important for the maintenance of grasslands. There is some concern that on-going climate change will exacerbate the number, size, and frequency of wildland fires as some ecosystems transition to new stable states. For example, California chaparral and conifer forest ecosystems are undergoing unprecedented drought related mortality, and anticipated regime shifting wildfires in the next several decades.

Summary of how this NCP is produced:

- ***Indirect***: Prevention of air pollution emissions from ecosystems
- ***Indirect:*** Stabilization of soils to prevent dust production
- ***Direct***: Deposition of air pollutants on plants and ecosystem structures
- ***Direct***: Absorption of air pollutants by plants and further metabolic transformation by plant metabolism and decomposition by microorganisms
- ***Direct***: Emission of air pollutants

3.3.2. How is it measured?

Air quality is measured through the evaluation of the concentration of different air pollutants in the atmosphere. The contribution of nature to regulate air quality can ben indirectly measured by the evaluation of carbon stocks in ecosystems, which can be a proxy of the prevented emission of air pollutants like fine particular matter and carbon monoxide that can be released when biomass is burned as direct consequence of anthropogenic activities, like burning agricultural waste and peatlands, using firewood, draining wetlands, and forest fires. Another indirect way to measure this contribution is through the evaluation of vegetation cover of areas susceptible to dust emissions (Engelstaedter et al. 2003), and associated modelling analysis of the impact of vegetation cover and structure on dust emissions and movement. The direct contribution of ecosystems to air quality through the deposition of air pollutants on plants and ecosystem structures can be assessed by direct measures of deposition on plant surfaces, mass balance approaches evaluating changes in air quality up and down wind of ecosystems, and proxies including plant stature, leaf surface area, and other ecosystem characteristics. Some studies have tested for particulate absorption through sampling leaves and examining the residue washed from trees (Powe and Willis 2004).

3.3.3. Links to other NCPS

NCP 2 – Pollination and dispersal of seeds and other propagules: air quality affects pollinators and seed dispersers activity, and consequently their mutualistic interactions with plants

NCP 4 – regulation of climate: Prevented emissions of air pollutants through biomass burning and draining of wetlands is also effective to prevent the emissions of greenhouse gases, such as carbon dioxide, methane, and nitrogen oxides. At the same time, vegetation recovery – especially forests – can help in the deposition and absorption of air pollutants and to sequester carbon in biomass, thus contributing to both air quality and climate regulation

NCP 12 – food and feed: ozone impacts negatively crop production and animal husbandry, so as the potential of these activities to provide food and feed

NCP14 – Medicinal, biochemical and genetic resources: Medicinal plants quality potentially highly impacted by air quality because any polluted particles that are absorbed are likely to affect the effect people's (an animal) health

NCP 15 – learning and inspiration: Air quality affects ability to take advantage of non-material NCP, especially those associated to open-air activities

NCP 16 – Physical and psychological experiences: Air quality affects ability to take advantage of non-material NCP, especially those associated to open-air activities

NCP 17 – Identity: Air quality affects ability to take advantage of non-material NCP

3.3.4. Indicators of NCP joint production

NCP	Production Function	Indicator/ Proxy	Rationale/ justification for why we this indicator/ proxy was selected	Data set	Scale of Measure – space	Scale of measure - time
Air quality regulation	Prevention of air pollution emissions	Carbon stocks in ecosystems	The amount of air pollutants like fine particulate matter and carbon monoxide that is released from biomass burning and land use conversion is directly associated to above-ground biomass stocks	https://www.arcgis.com/home/item.html?id=cd448873b75148638095e599166e5055	Global	2000
		Prevented emissions from biofuel use	The use of biofuel instead of fossil fuels reduce the net emissions of fine particulate matter in the air	Hill et al. 2009	United States	2005
	Mitigation of soil dust emissions	Vegetation type and cover in areas prone to soil dust emission	Vegetation protect soils against wind erosion, thus preventing the emissions of soil dust to the air	Tegen et al. 2002	Global	1982–1993

	Mitigation of dust storms	Vegetation leaf area index (LAI)	Dust storm frequency is inversely correlated to LAI (Engelstaedter et al. 2003)	Zhu et al. 2013	Global	1982–1993
	Deposition and absorption or air pollutants by plants	Vegetation leaf area index (LAI)	Vegetated areas with higher LAI values have a higher surface roughness, structural complexity, and density of leaves, which contribute to intercept air pollutants and favor their further deposition and absorption	Zhu et al. 2013	Global	1981-2011
	Deposition and absorption or air pollutants by plants	Leaf properties	Leaf hairiness, stickiness, thickness, and optical porosity define their capacity to intercept air pollutants and favor their further deposition and absorption	TRY database	Local	Not applied
	Particulate matter deposition by vegetation	Vegetation type and cover in areas prone to soil dust movement	Vegetation barriers reduce wind turbulence, and increase the amount of deposition, as the concentration of dust is high when the plume impacts on the vegetation and as the full height of the plume passes through the barrier.	Tegen et al. 2002	Global	punctual

3.3.5. Trends in joint production

3.3.5.1. General (across all units of analysis)

Narrative review based on literature (500-2000 words)

Land use changes that reduce vegetation structure or complexity such as deforestation, reduce the regulation of air quality. Land changes that reduce protection of the land surface result in dust production, reducing air quality; dust production has doubled over the past 100 years (Mahowald et al. 2010; Mulitza et al. 2010). On the other hand, land use changes that establish a more developed vegetation structure, like agroforestry, afforestation, restoration, have the potential to improve air quality. Management of ecosystems is also critical to nature's regulation of air quality. Regulation of air quality is to some extent a function of loading, so more of this NCP is produced in places with higher levels of air pollution. Land management such as harvest, which may be done in a way that moves dust into the air, and biomass burning, such as rice straw burning in India or peat burning in Indonesia, also reduce air quality, mainly due to the emissions of fine particulate matter. The impacts of biomass burning on premature mortality linked to outdoor air pollution is high (Lelieveld et al. 2015).

<u>*Summary of NCP trends*</u>:

- ***Trend***: Overall up. More pollution = more air quality regulation. Deforestation reduces air quality regulation.
- ***Spatial variance***: Large variance – background state of air quality is very different around the world, regulatory effects are strongly related to specific vegetation characteristics and weather patterns.
- ***Degree of certainty***: Moderate. Air quality is widely measured but the contributions of ecosystems to regulating it are not.

Output of the joint production Potential Nature's Contributions

Indicator	Concentration of air pollutants in the air	Retention and prevented emissions of air pollutants by ecosystems
Trend During the last 50 years: 2 = Major increase (>20%) 1 = Increase (5% to 20%) 0 = No change (-5% to 5%) -1 = Decrease (-20% to -5%) -2 = Major decrease (< -20%)	-1 (there is a global pattern of increased emissions of fine particulate matter, black carbon, nitrogen, sulfur oxides, and ozone – OECD 2016), but these patterns are concentrated in highly populated regions – mostly in Africa and Asia - and are not widespread distributed across the globe.	-1 (the contributions of nature to retain and prevent emissions of air pollutants have been compromised through widespread firewood and biomass burning, deforestation, and agriculture in several regions, although forest transitions have improved Nature conditions to ameliorate air quality (Lelieveld et al. 2015).
Spatial variance 3 = opposite trends in different regions 2 = same directional trends in different regions but of contrasting magnitude 1 = similar trends all over the world	3 (air pollution has increased more remarkably in Asia, but it is reducing in previous industrial regions of America and Europe)	3 (Natural forest area declined ~6% from 1990 to 2015. But whereas some global regions – mostly developed countries – are experiencing forest transitions and tree cover gains, deforestation still prevails in most developing countries)
Degree of certainty 4 = Well established: Robust quantity and quality of evidence & High level of agreement 3 = Established but incomplete: Low quantity and quality of evidence & High level of agreement 2 = Unresolved: Robust quantity and quality of evidence & Low level of agreement 1 = Inconclusive: Low quantity and quality of evidence & Low level of agreement	4 (there are several monitoring networks assessing air pollutants concentration globally, with reports being presented yearly)	3 (it is well established that deforestation, biomass burning, and intensive agriculture releases large amounts of air pollutants in the atmosphere, and that vegetation has the potential to protect soils and prevent air dust emissions, and trap some air pollutants in plant parts)
The two most important papers supporting the reported trend	World Health Organization. 2016. Ambient air pollution: A global assessment of exposure and burden of disease. Organization for Economic Cooperation and Development.	Keenan, R. J. et al. (2015). Dynamics of global forest area: Results from the FAO Global Forest Resources Assessment. Forest Ecology and Management 352: 9–20

2016. The economic consequences of outdoor air pollution. OECD Publishing, Paris.

Tegen I. et al. (2002) Impact of vegetation and preferential source areas on global dust aerosol: Results from a model study. J. Geophys. Res. 107:4576

Janhäll, S. (2015) Review on urban vegetation and particle air pollution - Deposition and dispersion. Atmospheric Environment 105, 130e137.

3.3.5.2. By Units of Analysis

1. Tropical and subtropical dry and humid forests	Down	Tropical forests experienced a net loss of 5.5 $M.ha.y^{-1}$ from 2010-2015, but sub-tropical have had a modest gain of 0.089 $M.ha.y^{-1}$ in the same period (Keenan et al. 2015). Tropical and sub-tropical forests are, by far, the terrestrial ecosystems with the largest carbon stocks, so their destruction and degradation releases large amounts of particulate matter and other pollutants in the air. Complementary, intensive agriculture has expanded in this unit of analysis, which has fostered the emissions of other pollutants in the air.
2. Temperate and boreal forests and woodlands	Up	Temperate regions have experienced forest transitions, with the ongoing conversion of pasturelands and croplands to forests. Temperate forests have experienced a net gain of 2.2 M ha y-1 of forests, but forest area has been relatively stable in boreal regions (Keenan et al. 2015). Consequently, biomass burning as part of land use change has not been a major driver of air pollution in this unit of analysis.
3. Mediterranean forests, woodland, and scrub	Down	Land abandonment and fire suppression have favored woody encroachment in Mediterranean ecosystems, which have increased their role as carbon sinks. However, climate change have increased the magnitude of forest fires and the emissions of greenhouse gases.
5. Tropical and subtropical savannahs and grasslands	Down	The widescale conversion of ecosystems in this unit of analysis to agriculture and planted pastures, and potential increase in wild fires caused by climate change, has increased the emissions of air pollutants
6. Temperate grasslands		
7. Drylands and deserts	Down	Climate change has increased the aridity in this unit of analysis, which exacerbate land degradation and desertification (Huang et al. 2017), which has favored the emission of dust
8. Wetlands – peatlands, mires, bogs	Down	These ecosystems have been widely drained for establishing cultivated areas and infrastructure, which has increased the vulnerability of peat fires (Turestsky et al. 2015) and the emissions of air pollutants.
9. Urban/semi-urban	Down	Urban and semi-urban regions are major sources of air pollution, and the ongoing expansion of cities and dependency on fossil fuels have worsed the situation.
10. Cultivated areas (including cropping, intensive livestock, farming, etc.)	Down	Increase in the global production of chicken, pork, and beef to meet the tremendous rise of meat consumption globally (Fiala 2008), and the intensification of agriculture (Newbold et al. 2016) has contributed to increase the air pollution emissions in this unit of analysis.

3.4. Impacts on good quality of life

3.4.1. Different types of value

3.4.1.1. What is the NCP contribution

This NCP contribute to good quality of life by reducing premature death and health problems associated to air pollution. Air pollution has both acute and chronic effects on human health, affecting a number of different systems and organs. It ranges from minor upper respiratory irritation to chronic respiratory and heart disease, lung cancer, acute respiratory infections in children and chronic bronchitis in adults, aggravating pre-existing heart and lung disease, or asthmatic attacks (Chen and Kan 2008; Kampa and Castanas 2008; Zhang et al. 2014). Short- and long-term exposures have also been linked with premature mortality and reduced life expectancy (Biggieri et al. 2004), while long-term effects of air pollution on the onset of diseases such as respiratory infections and inflammations, cardiovascular dysfunctions, and cancer is widely accepted (Yamamoto et al. 2014; Zhang et al. 2014). These health problems have direct negative economic impacts on economy, in terms of healthcare costs and reduced activity days. Economic setbacks also includes the costs associated to flight delays, airport closure, and accidents resulted from reduced visibility, deteriorated infrastructure (e.g., due to the superficial accumulation of black carbon), and overall malfunctioning of transport systems.

The maintenance of air quality due to the prevention of new emissions resulted from biomass burning, agriculture, dust emissions from soils, and other sources or emissions resulted from anthropogenic impacts on ecosystems, combined with the capacity of vegetation to deposit and absorb air pollutants, can effectively contribute to reduce the incidence and severity of health problems caused by air pollution, as well their economic consequences.

3.4.1.2. How do we measure that value/contribution?

The contribution of this NCP can be valued in terms of the reduced incidence and severity of human health problems caused by air pollution, their economic impacts on the costs associated to healthcare and reduced activity days, infrastructure maintenance, and malfunctioning of transport systems.

3.4.1.3. Substitutability

Filters can be used to purify the air indoor, people can use masks to prevent the inhalation of some air pollutants and use air humidifiers to mitigate indoor fine particulate matter suspension, and can change production processes to reduce air pollution.

3.4.1.4. Status and Trends in impact (value)

There are widespread reported values of the negative consequences of air pollution, but not about the reduction of these consequences resulted from nature contributions in regulating air quality. The only study found reported costs savings of £17,000-£900,000 attributed to the estimated reduction of 5-7% in number of deaths, and of 4-6% in hospital omissions, caused pollution absorption by England woodlands (Powe and Willis 2004).

3.4.2. Indicators of NCP impact

3.4.2.1. Indicators by value

Value type	Indicator/ Proxy	Rationale/ justification for why we this indicator/ proxy was selected	Data set	Scale of Measure – space	Scale of measure - time
Health	Amelioration of health problems caused by air pollution resulted from ecosystem contributions to air quality	Air pollution cause several health problems on people, so air pollution reduction by ecosystems may help to ameliorate people' health	Powe and Willis 2004	Local (England)	1999
	Reduction in the number of deaths caused by air pollution reduction by ecosystems	Air pollution cause several health problems on people that led to premature death, so air pollution reduction by ecosystems may help to prevent such premature deaths	Powe and Willis 2004	Local (England)	1999
	Premature deaths caused by pollution emissions by natural sources, biomass burning, firewood use and agriculture		Lelieveld et al. 2015	Global	2010
Economic	Cost reduction with healthcare resulted from ecosystem contributions to air quality	Air pollution cause several health problems on people imply costs in terms of healthcare costs and reduced activity days; so air pollution reduction by ecosystems may help to reduce the costs associated to such health problems	Powe and Willis 2004	Local (England)	1999
Economic	Cost reduction associated to prevented deaths caused by air pollution as consequence	Air pollution cause several health problems on people that led to premature death, which in turn imply in costs in terms of ; so air pollution reduction by ecosystems may help to	Powe and Willis 2004	Local (England)	1999

	of ecosystems' deposition of air pollutants	reduce the costs associated to such premature deaths			

3.4.2.2. Trends by user group

User Group	**Direction of arrow**	**Rationale/ justification for why you think this trend is happening**
Universal	down	Increasing pollution emission from land use change, agriculture, and biomass burning in most part of the world
subsistence and small scale harvesting	down	Increasing pollution emission from land use change and firewood use
commercial harvesting	down	Increasing pollution emission from land use change and intensive agriculture practices, and reduced mitigation potential from ecosystems due their progressive destruction and degradation
Industrial, commercial, and service professional	down	Reduced mitigation potential of air pollution from ecosystems, mostly forests, due their progressive destruction and degradation in highly populated and industrial regions
Urban	down	Reduced mitigation potential of air pollution from ecosystems, mostly forests, due their progressive destruction and degradation in highly populated and industrial regions
Rural	down	Increasing pollution emission from land use change, biomass burning, firewood use, and intensive agriculture practices, and reduced mitigation potential from ecosystems due their progressive destruction and degradation

	Impact of Output of Joint Production on Good Quality of Life by Major Social Group
Indicator	Health and economic problems caused by air pollution
Trend During the last 50 years: 2 = Major increase (>20%) 1 = Increase (5% to 20%) 0 = No change (-5% to 5%) -1 = Decrease (-20% to -5%) -2 = Major decrease (< -20%)	-2 (nearly 3.3 million premature deaths annually have been attributed to air pollution (Amann et al. 2013). One ninth of the global deaths in 2012 were caused by air pollution, and only about a tenth of people are estimated to breath clean air (WHO 2016). Health problems associated to air pollutions are associated to major economic losses in economies worldwide (healthcare costs and reduced activity days - OECD 2016)
Variance across social groups 3 = opposite trends for different groups	2 (rural and urban groups from developing countries have had declines on air quality associated to firewood and stubble burning, deforestation and air pollution in cities,

2 = same directional trends for different groups but contrasting magnitudes 1 = similar trends for all social groups	while for urban groups of developing countries air quality has improved)
Spatial variance 3 = opposite trends in different regions 2 = same directional trends in different regions but of contrasting magnitude 1 = similar trends all over the world	3 (premature mortality and health problems caused by air pollution increased remarkably in Asia, but it is reduced in previous industrial regions of America and Europe)
Degree of certainty 4 = Well established: Robust quantity and quality of evidence & High level of agreement 3 = Established but incomplete: Low quantity and quality of evidence & High level of agreement 2 = Unresolved: Robust quantity and quality of evidence & Low level of agreement 1 = Inconclusive: Low quantity and quality of evidence & Low level of agreement	4 (it is well established that air pollutants, including that resulting from ecosystem degradation, impact negatively human health, which have in turn direct impacts in the economy)
Two to five most important papers supporting the reported trend	Levelied, J. et al. (2015) The contribution of outdoor air pollution sources to premature mortality on a global scale. Nature 525(327) Organization for Economic Cooperation and Development. 2016. The economic consequences of outdoor air pollution. OECD Publishing, Paris.

3.5. Summary

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 are higher in Asia, but reductions have occurred in previously industrial regions of America and Europe. Nature's contribution to air quality emissions through deforestation, biomass burning, and intensive agriculture that release large amounts of air pollutants are well established. 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. Because all of these functions are provided mostly by a well-developed vegetation structure and conserved ecosystems, nature's contribution to retaining and preventing emissions of air pollutants has been compromised through widespread firewood and biomass burning, deforestation, and agriculture (Lelieveld et al. 2015). Globally, global tree cover increased 7.2% from 1982-2016 (Song et al. 2018), but natural forest area declined ~6% from 1990 to 2015; natural forest loss and gain was distributed unevenly, with some global regions – mostly developed countries –experiencing forest transitions and tree cover gains while deforestation prevails in most developing countries.

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3.7. Search methodology

Database: Web of Knowledge.

Search strings:

(1) "air quality" AND ("sulphur oxide" OR "nitrogen oxide" OR nox) AND (review OR synthesis OR "meta-analysis" OR "state of art" OR overview)

(2) "air quality" AND (ozone OR "O3" OR "UV-B") AND (review OR synthesis OR "meta-analysis" OR "state of art" OR overview)

(3) "air quality" AND pollutant AND (filtrat* OR fix* OR degrad* OR stor* OR absorpt*) AND (review OR synthesis OR "meta-analysis" OR "state of art" OR overview)

(4) "air quality" AND "human health" AND (review OR synthesis OR "meta-analysis" OR "state of art" OR overview)

(5) "air quality" AND (biogenic OR "volatile organic compound" OR "voc" OR particulates OR aerosol) AND (review OR synthesis OR "meta-analysis" OR "state of art" OR overview)

Total hits for each string

(1) 120

(2) 383

(3) 59

(4) 177

(5) 748

Papers that were not considered: methodological procedures to measure compounds, models, simulations, indoor air quality, mitigation, innovative methods to reduce air pollution.

After filtering by review, reviewing abstracts, removing duplicates and papers without access, total papers downloaded and reviewed: 81

4. NCP 4: Regulation of Climate

Primary Author: Pedro Brancalion

4.1. IPBES Definition:

Climate regulation by ecosystems through positive or negative effects on emissions of greenhouse gases, biophysical feedbacks from vegetation cover to atmosphere, direct and indirect processes involving biogenic volatile organic compounds (BVOC), moisture recycling, and regulation of aerosols and their precursors.

4.2. Why is this NCP important?

4.2.1. What is the big environmental issue this pertains to?

Climate has been historically regulated by ecosystems through their influences in the fluxes of gases to, and physical interaction with, the atmosphere, but the intense use of fossil fuels and the destruction and degradation of ecosystems have changed global climatic patterns and compromised biodiversity and people's good quality of life.

4.2.2. How does this NCP play a role?

Life on Earth, including all aspects of human survivorship and experience, is dependent on climate. Climatic patterns are governed by complex interactions and biophysical feedbacks in the biosphere, which have been shaped since the beginning of life. Climate governs the spatial distribution and amount of existing ecosystems and species (e.g. Sitch *et al.,* 2008; Bellard *et al.,* 2012). However, climate has changed fast in the last century, with dramatic consequences for biodiversity and people's good quality of life (Hanewinkel *et al.*, 2012). Increased frequencies of extreme weather events like droughts and floods, sea level rise, proliferation of diseases, crop failures, and degradation of natural ecosystems providing critical resources to people are just some of the many negative consequences of contemporary climate change to human wellbeing. Ecosystems play an utmost role for regulating climate and, if adequately conserved, managed, and restored, can help to mitigate the impacts of human-mediated climate changes.

4.3. Joint production

4.3.1. How is this NCP produced?

Climate is regulated by ecosystems mainly through their influences in the fluxes of greenhouse gases, water, and biogenic volatile organic compounds in the atmosphere, and modification of albedo (Meir et al., 2006; Laothawornkitkul et al., 2009; Arnet et al., 2010; Smith et al., 2013, among others).

Regarding the fluxes of greenhouse gases, atmospheric CO_2 concentration is partially controlled by the large amount of carbon stored in terrestrial vegetation (e.g. IPCC AR5, 2013), while CH_4 and NO_2 is influenced by livestock activity in agroecosystems (Benckiser et al., 2015; Forabosco et al. 2017) and decomposition of organic matter in wetlands (O'Connor et al., 2010; Laanbroek, 2010; Pester et al., 2012; Abdalla et al., 2016; Hamdan and Wickland 2016, but also see Karakurt et al. 2012 and Yusuf et al., 2012). Land use change and agriculture are responsible for ~20-30% of global emissions of greenhouse gases. In fact, year-to-year variations in atmospheric CO_2 have been shown to be mainly driven by terrestrial biosphere CO_2 budget (Le Quéré *et al.*, 2009). Consequently, the sequestration of atmospheric CO_2 by reforestation has been indicated as the most low-cost mitigation solution to achieve the Paris Climate Agreement goal of holding warming to below 2°C (Griscom et al. 2017). At the same time, land use changes and conversion of natural vegetation to agriculture or urban areas also correspond to net releases of CO_2 in the atmosphere (Houghton et al., 2017), and BVOCs (Rosenkranz et al., 2015). Climate-mediated changes in vegetation phenology (e.g. budburst, green-up season, yellowing), also affect regional climate and CO_2 budget and surface temperature (Myneni *et al*., 1997; Richardson et al., 2013). In turn, changes in ecosystem functioning will affect climate at various scales, through various biophysical processes. These biophysical feedbacks are largely controlled by leaf area index (LAI), which are highly linked to land use changes and regulates the amount of absorbed solar radiation by modifying albedo and the magnitude of evapotranspiration through canopy resistance (Lashof et al., 1997). An increase in LAI enhances vegetation evapotranspiration, which cool the surface temperature (Shukla & Mintz, 1982), while it decreases albedo, which can warm surface temperature (Betts, 2000; Lee *et al.*, 2011). Beyond these two opposing effects, changes in LAI also affects atmospheric circulation, shortwave transmissivity and longwave air emissivity, which turns its net effect on climate hard to predict and quantify (Zhu *et al.*, 2016).

As consequence of the LAI changes and associated biophysical feedbacks, vegetation cover strongly impact temperature patterns (Luyssaert et al., 2014; Lawrence & Vandecar 2015; Alkama & Cescatti 2016; Naudts et al. 2016; Sabajo et al. 2017). The net effects of ecosystems on regional and global climate warming and cooling depend on the relationships among the rate and magnitude of potential evapotranspiration production, the changes to surface and cloud albedo, and land cover change impacts on aerosols and reactive gases (Ellison et al. 2016). For instance, evaporation and transpiration under tree shade may reduce sensible heat, thus temperature remains much cooler during daytime (Pokorný et al. 2010; Maes et al. 2011; Hesslerová et al. 2013). However, forests may reduce albedo, potentially contributing to local warming under more cloud-free skies, particularly at high latitudes in winter (Lee et al. 2011; Li et al. 2015). But additional regional and global cooling may results from emissions of reactive organic compounds (Spracklen et al. 2008) by forests, which can increase low-level cloud cover and radiation reflectivity (Ban-Weiss et al. 2011; Heiblum et al. 2014). The complexity of these relationships is actually lost in much current research that looks individually at some of these factors (Ellison et al. 2016; Naudts et al. 2016).

Most of the aforementioned influences of ecosystems in temperature and albedo patterns are accompanied by impacts on the circulation of moisture in the atmosphere. Moisture recycling is broadly defined as the evaporation rising from vegetation, flowing through the atmosphere and then falling as precipitation somewhere else (Keys et al. 2016). Vegetation plays a relevant role in moisture recycling because plants maximize the flow of water from soils to the atmosphere, then contributing to produce rain at regional scales (Seneviratne *et al*., 2010). Climate regulation by moisture recycling results from partial regulation of rainfall timing, magnitude, and, to some extent, location. Recent studies show that vegetation transpiration not only contribute water for rainfall, but drives seasonal rainfall cycle by increasing shallow convections that moistens and destabilizes the atmosphere (Wright *et al.*, 2017), and by shifting general circulation (Swann *et al.*, 2012). Vegetation cover was also reported to impact cloud climatology through its impact on the atmospheric boundary layer (Wang *et* *al.*, 2009).

In marine ecosystems, primary marine organic aerosols, like dimethyl sulphide emitted by algae, is supposed to increase cloud condensation nuclei in the marine boundary layer and promote the formation of clouds (Gildor & Follows 2002), which increase the overall albedo of oceans and, consequently, part of the solar energy that reaches the Earth is reflected back to space and reduce the greenhouse effect (Bigg et al., 2003). However, these effects are poorly known and not linearly related to biological productivity in the ocean (Quin *et al.* 2015). Another mechanism through which oceans regulate the climate is the climate-weathering feedback (Faharat *et al.* 2014). Chemical weathering of marine Ca–silicate rocks removes CO_2 from the atmosphere, resulting in the precipitation of carbonates in oceans. Therefore, oceans contribute to climate regulation by removing atmospheric CO_2, the most important greenhouse gas. In marine ecosystems, microalgae have been proposed as a CO_2 removal option to contribute to climate change avoidance and problems coming from the use of fossil fuels, but they do not permit long-term CO2 storage because they are easily decomposed (Acién Fernández et al., 2012).

Overall, ecosystems impact fundamental biophysical processes controlling climate on Earth, but these impacts on climate regulation are essentially indirect, and depend on how multiple processes interact with each other in the whole system.

Summary of how this NCP is produced:

- ***Indirect***: CO_2 sequestration by vegetation reduce the greenhouse effect
- ***Indirect***: removal of atmospheric CO_2 by chemical weathering of marine Ca–silicate reduce the greenhouse effect
- ***Indirect***: greenhouse gases emissions from and sequestration by wetlands
- ***Indirect***: the maximization of water flow from soil to atmosphere by vegetation promotes moisture recycling
- ***Indirect***: albedo changes mediated by vegetation cover influences temperature
- ***Indirect***: biological compounds favor cloud formation, which change albedo and moisture recycling

4.3.2. How is joint production of this NCP measured?

Climate regulation by ecosystems is difficult to be measured through direct observations, since changes in climate result from the combination of many factors, such as changes in greenhouse gases concentrations, annual and seasonal climate variability, and ecosystem functions. However, observations at both site-scale (greenhouse gas fluxes, biomass changes, temperature variation) and regional to global scales (using remote sensing) have been conducted to estimate the fluxes of greenhouse gases and aerosol emissions due to land use and land cover changes. Using these estimated fluxes/emissions as a boundary condition, mechanistic models (e.g. atmospheric general circulation models) are used to estimate how changes in ecosystems regulate climate (e.g. Claussen et al. 2001; Takata et al. 2009). Frequently used indirect measures are:

Climate regulation by terrestrial ecosystems:

- Direct measurements
    - Direct monitoring of greenhouse gases emissions/sequestration through flux towers (Martin et al 2001);
    - Assessments of vegetation and soil carbon stocks through field inventories;

- Direct monitoring of temperature and use of thermal imageries (i.e. satellite measurements of land surface temperature) resulted from land cover and land use changes;

- Proxy measures
  - Estimation of vegetation and soil carbon stocks through imagery work and use of specialized sensors;
  - Evaluation of albedo and potential evapotranspiration through LAI;
  - Evaluation of air concentration of biogenic volatile organic compounds in different ecosystem portions.

- Models
  - Climate change models
  - Estimation of vegetation and soil carbon stocks through "data assimilation" (i.e. a robust mathematical framework for improving model predictions with observational data) (Scholze et al. 2017)
  - Plant growth feedback models

Climate regulation by oceans:

- Air–sea and sediment–water fluxes of carbon and CO_2 (modeled or empirically determined);
- Air–sea fluxes of other greenhouse gases such as dimethyl sulfide, methane, nitrous oxide (modeled or empirically determined);
- Levels of carbon in different components of the marine ecosystem (modeled or empirically determined carbon levels: biomass of carbon; dissolved organic or inorganic carbon; suspended organic or inorganic carbon; buried particulate organic or inorganic carbon;
- Permanence of carbon sequestration measured as percentage of annual carbon turnover from sediments;
- Net primary production.

4.3.3. Links to other NCPS

Climate affects all biological and physical process on Earth, so all NCPs are directly or indirectly affected by climate regulation by ecosystems.

NCP2 – pollination: climate impacts the diversity and activity of pollinator communities, as well the phenology of flowering plants, and may disrupt the interaction between flowering plants and pollinators;

NCP3 – air quality: air humidity and circulation controls the concentration and deposition of dust and particulate matters, which are the major causes of incident premature mortality caused by outdoor air pollution (Lelieveld et al. 2015). BVOCs also affect local air quality;

NCP5 – ocean acidification: increased air temperatures and CO_2 concentration favor CO_2 absorption by the ocean, which dissolves to form carbonic acid, the main driver of ocean acidification;

NCP6 – water quantity: climate regulate the amount, duration, frequency, and spatial distribution of precipitation and ice melting, which directly impact the supply of water to people;

NCP7 – water quality: the amount, duration, frequency, and spatial distribution of precipitation also influence siltation of watercourses by sediments brought by runoff, while temperature affects the activity of the aquatic biological community in charge of water purification or releasing toxic compounds;

NCP8 – soils: precipitation and wind patterns impact soil erosion, while rainfall also influence the production potential of soils through the regulation of the supply of water to plants;

NCP9 – hazards: the most common hazards (e.g. flooding, extreme droughts, hurricanes, extreme snowstorms, landslides, wildfires, heat waves) are directly associated to climate;

NCP10 – pests: insect populations are affected by environmental conditions controlled by climate. With climate change, the population of certain insects can be favored and the problems they cause be amplified. There are several examples of pests outbreaks causing widespread mortality of temperate tree species, and the increase of the frequency and magnitude of such phenomena in the past few years has been attributed to climate change. Similarly, some disease vectors have expanded their range as response to climate change;

NCP11 – energy –, NCP12 – food –, NCP13 – materials –, NCP14 – medicine: the development of all organisms supplying energy, food, materials or medicine to humans, both in cultivated and in natural ecosystems, rely on appropriate temperature and humidity conditions, which are controlled by climate. If the Nature contribution to regulate climate is hampered, climate may change in a detrimental way to production or managed systems. Energy production, in particular, has a big impact on the emissions of greenhouse gases;

NCP15 – learning, NCP16 – experiences, NCP17 – identities: many human experiences are closely linked with the environmental conditions in which human populations have developed for a long time. For instance, several traditional and indigenous groups have rituals, ceremonies, and gods associated to Nature cycles and phenomena, linked to the beginning of the rainy season (which is also the sowing season), with extreme events such as hurricanes and droughts, and seasonal variations in ecosystems, which are all controlled by climate and its interaction with the living world.

4.3.4. Indicators of NCP joint production

NCP	Production Function	Indicator/ Proxy	Rationale/ justification for why we this indicator/ proxy was selected	Data set	Scale of Measure – space	Scale of measure - time
Climate regulation (vegetation)	CO_2 removal from the atmosphere	Vegetation-atmosphere CO^2 exchange	CO_2 exchange between vegetation and atmosphere partly determine CO_2 atmospheric concentration and CO_2 forcing on climate	*(Baldocchi et al., 2001)*	global	Past 40 years
	CO_2 removal from the atmosphere	Below- and above-ground biomass stocks	The increase of vegetation biomass relies on the absorption of atmospheric CO_2, the main greenhouse gas	*Saatchi et al. 2011; Baccini et al. 2012*	Tropical regions	present
	Biophysical feedback on climate	Leaf area index	LAI has a strong impact on CO_2 exchanges, evapotranspiration and surface temperature	*(Fang et al., 2012)*	Global	Past 40 years
	Biophysical feedback on climate	Biomass changes	CO_2 sequestration in biomass contribute to the mitigation of atmospheric CO_2 rising and CO_2 forcing on climate	*(Pan et al., 2011)*	Global	Past 50 years
	Biophysical feedback on climate	Remote sensing	Satellite-based data are currently at the core of our understanding of the effect of vegetation on land	*(Swann et al., 2012; Wright et al., 2017)*	Regional to Global	Past 40 years

			temperature surface and precipitations			
	Biophysical feedback on climate	Mechanistic models	Models allow quantify and disentangling effects of vegetation on climate and hydrological cycle	*(Zeng et al., 2017)*	global	unlimited
	Vegetation impact on atmospheric cloudiness	Atmospheric sounding	Allow quantifying the impact of vegetation on the vertical distribution of physical properties of the atmospheric column	*(Wang et al., 2009)*	Local to Regional	Past 40 years
	Vegetation-mediated enhancement of infiltration	Infiltrability	Infiltrability allows quantifying the impact of vegetation on infiltration and hydrological cycle	*(Nyberg et al., 2012)*	Local	Past 100 years
	Vegetation mediated temperature regulation	Air temperature Low-cost thermal imagery	Knowledge of energy cycle impacts can help target microclimatic cooling, as well as precipitation-recycling effects.	*(Ellison et al. 2016)*	Local to global	
	Carbon sinks	Soil organic carbon	Soil organic carbon is an important component of carbon stocks in terrestrial ecosystems, which control the fluxes of CO_2 to the atmosphere. Soil organic carbon concentration are determined in samples and extrapolated in various ways to represent a larger geographic area	*(Conant et al. 2011)* *(Eyles et al. 2015)*	Agricultural lands and Australia	
	Biophysical feedback on climate	Dust emissions	Dust aerosols may act as cloud or ice condensation nuclei, which indirect impacts on albedo, rainfall patterns, and CO_2 absorption by marine phytoplankton	*(Wang et al. 2017)*	Drylands	
Avoided emissions	Net reductions of greenhouse gases emissions	Net greenhouse gases emissions	The use of biofuels instead of fossil fuels can reduce the net emissions of greenhouse gases emissions	*(Hill et al. 2009)*	United States	2005
Climate regulation - oceans (biologically-linked)	Direct measures	Air–sea and sediment–water fluxes of carbon and CO_2	Proposed by Hattam et al. 2015; Widely measured	*Air-sea flux (Takahashi et al. 2009)* *http://cdiac.ornl.gov/oceans/LDEO_Underway_Database/air_sea_flux_2010.html* *Upper ocean-sediment flux of organic carbon (Le Moigne et al. 2013)* *https://doi.pangaea.de/10.1594/PANGAEA.809717* *(Bigg et al. 2003)*	Global Global	Ref year 2000 1985-2013 coverage where data available
		Air–sea fluxes of other greenhouse gases such as dimethyl sulfide	Proposed by Hattam et al. 2015; Widely measured	*(Bigg et al. 2003)* *(Bhatt et al. 20140* *(Gildor & Follows 2002)*	Global	

		Dissolved organic carbon; Suspended organic carbon	Proposed by Hattam et al. 2015; Widely measured			
		CO_2 removal from atmosphere	CO_2 removal by microalgae	*(Acién-Fernández et al. 2012)*	Global	
	Indirect measures	Net primary production	Indicates community changes that may alter ecosystem productivity	*http://www.science.oregonstate.edu/ocean.productivity/index* *World Ocean Assessment, Chapter 6*	Global	2003 onwards
	Indirect measures	Abundance of sulfate reducing microorganisms	anaerobic methanotrophic Archaea oxidize CH4, a gas with high warming potential, to CO2 (~90% of biogenic methane in marine and coastal environments is consumed through anaerobic oxidation)	*(Hamdam and Wickland 2016)*	Global	
Climate regulation - freshwater	Indirect measures	Abundance of sulfate reducing microorganisms	Molecular analyses using dsrAB (encoding subunit A and B of the dissimilatory (bi)sulfite reductase)	*(Pester et al. 2012)* *(Hamdam and Wickland 2016)*	Wetlands	
	Carbon sinks	Carbon sequestration		*(Kaynali et al. 2010)*	Wetlands	

4.3.5. Trends in joint production

4.3.5.1. General (across all units of analysis)

Satellite data survey have highlighted a greening of the land surface for the past 30 years, as well as a global increase of leaf area index (Zhu *et al.*, 2016). Since leaf area index is a good proxy of the many biophysical processes that influence climate regulation by terrestrial ecosystems (e.g., moisture recycling, carbon sequestration, changes in albedo, fluxes of biogenic compound gases), as well of the land use changes impacting carbon stocking in terrestrial ecosystems, this is an evidence that the contribution of Nature to regulate climate may have increased in the past years. This greening of the Earth is in line with the increase in biomass stocks and growth observed in long-term forest inventories (Boisvenue & Running, 2006; Pan *et al.*, 2011), in spite of the ongoing decline of forest cover in tropical regions (Keenan et al. 2015), and the enhancement of vegetation-atmosphere CO_2 exchanges (Graven *et al.*, 2013). This increased photosynthetic removal of CO_2 from the atmosphere potentially impose a negative forcing on the climate system, mitigating climate changes. However, the fundamental biological process that determine the terrestrial CO_2 budget and atmospheric CO_2 concentration, photosynthesis and respiration, will both be affected by climate changes (Friedlingstein *et al*., 2013), and saturation signs were recently observed (Nabuurs *et al.*, 2013; Brienen *et al.*, 2015; Baccini *et al.*, 2017) worldwide.

In spite of the enhancement of climate regulation by increased leaf area index globally, the contribution of ecosystems to regulate climate has also decreased due to their destruction and degradation. Tropical forests – the ecosystems with the largest carbon stocks on Earth − have experienced a net loss of 5.5 $M.ha.y^{-1}$ from 2010-2015, whereas sub-tropical regions have had a modest gain of 0.089 $M.ha.y^{-1}$ in the same period (Keenan et al. 2015). In addition, droughts mediated by climate changes have eroded the carbon stocks of remnant forests and compromised their potential to act as a carbon sink to mitigate climate change (Anderegg et al. 2015; Brienen et al. 2015). Under drought conditions, tropical forests may become a source, rather than a sink, of CO_2 to the atmosphere (Gatti et al. 2014).

Summary bullet list of NCP trends *(your assessment and rationale, briefly):*

- **Trend** (& why): Increasing in terrestrial ecosystems due to a greening of the land surface.
- **Spatial variance** (& why): High spatial variance across the world, caused by variations in the rates of destruction/degradation and recovery of ecosystems and their inherent role and contribution in regulating climate.
- **Degree of certainty** (& why): High variance of certainty; tropical forests' destruction and droughts have reduced their contribution to regulate climate, but temperate forests re-growth and global increase of leaf area index have evidenced an increased contribution of other terrestrial ecosystems.

Indicator	Output of the co production Concentration of greenhouse gases in the atmosphere	Potential Nature's Contributions Prevented emissions and uptake of greenhouse gases by ecosystems
Trend During the last 50 years: **2 = Major increase (>20%)** **1 = Increase (5% to 20%)** **0 = No change (-5% to 5%)** **-1 = Decrease (-20% to -5%)** **-2 = Major decrease (< -20%)**	-2 (CO_2 atmospheric concentration– the major greenhouse gas – increased by 30% in the last 70 years, and other greenhouse gases have also increased (WMO 2016; IPCC 2014)	- 1 (Global biomass stocks of ecosystems have declined remarkably in the last decades (Erb et al. 2017). Although world's forests have represented a major sink of CO_2 (Pan et al. 2011) and global tree cover increased 7.2% from 1982-2016 (Song et al. 2018), the area of tropical forests – the terrestrial ecosystems with the largest carbon stocks – has continuosly declined (Keenan et al. 2015; Song et al. 2018). However, carbon uptake by remnant and recovering tropical forests has compensated emissions from deforestation, resulting in a neutral contribution of tropical forests to the global carbon cycle (Mitchard 2018). On the other hand, methane and nitrous oxide emissions have counterbalanced the cooling effects of net CO_2 uptake by terrestrial ecosystems (Tian et al. 2016).
Spatial variance **3 = oposite trends in different regions** **2= same directional trends in different regions but of contrasting magnitude** **1 = similar trends all over the world**	1 (the concentration of greenhouse gases in the atmosphere have followed a global pattern of increase, without site-specific changes)	3 (forests are the terrestrial ecosystems with the largest carbon stocks, and deforestation has shown high spatial variation globally. Forest cover have declined in tropical regions, is stable in boreal regions, increased slightly in sub-tropical regions, and increased consistently in temperate regions (Keenan et al. 2015; Song et al. 2018).
Degree of certainty	4 (All IPCC reports and scientific paper	3 (Although there are several IPCC rep

4= Well established: Robust quantit y and quality of evidence & High level of agreement **3 = Established but incomplete: Low quantity and quality of eviden ce & High level of agreement** **2= Unresolved: Robust quantity an d quality of evidence & Low level of agreement** **1 = Inconclusive: Low quantity and quality of eviden ce & Low level of agreement**	s demonstrating the increase of gre enhouse gases concentration in the atmosphere, using different method ological approaches, and its direct association to climate change)	orts and scientific papers demonstr ating the negative impacts of habita t destruction and other anthropoge nic activities affecting ecosystems o n greenhouse gases emissions, the c ontributions of ecosystems to uptak e these gases and partially compensate emissions is not yet well established)
The two most important papers sup porting the reported trend	IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Cha nge [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp. World Meteorological Organization Gree nhouse Gas Bulletin. The State of Green house Gases in the Atmosphere Based on Global Obs ervations through 2016. 2017	Erb et al., 2017. Unexpectedly large impact of forest management and grazing on global vegetation biomass. Nature 553, 73. Keenan et al., 2015. Dynamics of global forest area: Results from the FAO Global Forest Resources Assessment 2015. Forest Ecology and Management 352, 9-20. Mitchard, E.T.A. 2018. The tropical forest carbon cycle and climate change. Nature 559:527-53 Pan et al., 2011. A large and persistent carbon sink in the world's forests. Science 333, 988-993. Song et al. 2018. Global land change from 1982 to 2016. Nature Tian et al., 2016. The terrestrial biosphere as a net source of greenhouse gases to the atmosphere. Nature 531, 225.

4.3.5.2. By Units of Analysis

Unit of Analysis	**Direction of arrow**	**Rationale/ justification for why you think this trend is happening**
1. Tropical and subtropical dry and humid forests	Down	Tropical forests experienced a net loss of 5.5 M.ha.y^{-1} from 2010-2015, but sub-tropical have had a modest gain of 0.089 M.ha.y^{-1} in the same period (Keenan et al. 2015). Tropical and sub-tropical forests are, by far, the terrestrial ecosystems with the largest carbon stocks, so their destruction and degradation releases large amounts of greenhouse gases to the atmosphere and reduce their potential to regulate climate. Complementary, ecophysiology and biodiversity changes combined with forest degradation by drought and fire, may further compromise the contribution of the remaining tropical and subtropical forest cover to mitigate climate change (Lewis 2006). Changes in land use from deep-rooted, woody vegetation to pastures and crop fields reduce evapotranspiration for precipitation recycling.
2. Temperate and boreal forests and woodlands	Up	Temperate regions have experienced forest transitions, with the ongoing conversion of pasturelands and croplands to forests. Temperate forests have experienced a net gain of 2.2 M ha y-1 of forests, but forest area has been relatively stable in boreal regions (Keenan et al. 2015).

		Consequently, this unit of analysis has become a carbon sink and has pushed down the atmospheric concentration of greenhouse gases (Myneni et al. 2001).
3. Mediterranean forests, woodland, and scrub	Up	Land abandonment and fire suppression have favored woody encroachment in Mediterranean ecosystems, which have increased their role as carbon sinks. However, climate change have increased the magnitude of forest fires and the emissions of greenhouse gases.
4. Tundra and high mountain habitats	Down	Climate change has caused the melting of permafrost, which can release large amounts of carbon dioxide and methane to the air and reduce the contribution of this unit of analysis to regulate climate (O'Connor et al. 2010). In addition, the reduction of the area permanently covered by ice may impact the flow of humidity to certain regions and modify local climates. However, tundra has greened in the Artic in the last 20 years, which may have contributed to increase vegetation carbon stocks, increase albedo and moisture recycling (Sitch et al. 2007)
5. Tropical and subtropical savannahs and grasslands	Down	The widescale conversion of ecosystems in this unit of analysis to agriculture and planted pastures, and potential increase in wild fires caused by climate change, may erode carbon stocks. In addition, the replacement of native, deep-rooted vegetation by cultivated plants reduce the overall evapotranspiration and compromise moisture recycling.
6. Temperate grasslands	Up	Temperature increase and management practices have increased the net gain of carbon by these ecosystems (Chang et al. 2015).
7. Drylands and deserts	Down	Climate change has increased the aridity in this unit of analysis, which exacerbate land degradation and desertification, with negative impacts on vegetation and soil carbon stocks (Huang et al. 2017)
8. Wetlands – peatlands, mires, bogs	Down	These ecosystems have been widely drained for establishing cultivated areas and infrastructure. When drained, soil organic matter decomposition is enhanced and large amounts of CO_2 and CH_4 are release to the air, which reduce the contribution of these ecosystems to regulate climate. Climate change has also promoted a higher emission of CH_4 in wetlands (Limpens et al. 2008; O'Connor et al 2010). Complementary, climate change and human disturbances have increased the vulnerability of peat fires, which may convert wetlands into large sources of greenhouse gases emissions to the atmosphere (Turestsky et al. 2015).
9. Urban/semi-urban	Down	Urban and semi-urban regions are major sources of greenhouse gases emissions, and the ongoing expansion of cities and the associated demand for fossil fuels will likely worse climate change, in spite of the efforts to reduce the dependency on fossil fuels.
10. Cultivated areas (including cropping, intensive livestock, farming, etc.)	Down	Cultivated areas are expected to worse climate change due to the increase in the global production of chicken, pork, and beef to meet the tremendous rise of meat consumption globally (Fiala 2008), and the intensification of agriculture, which has led to increased conversion of natural ecosystems and use of fossil fuels and nitrogen fertilizers (Newbold et al. 2016).
11. Cryosphere	Down	Positive feedback mechanisms may enhance climate change impacts on cryosphere, which melting may led to its destabilization and consequent larger impacts on the global climatic systems (Prăvălie 2016).
12. Aquaculture areas	Down	The expansion and intensification of aquaculture globally have promoted the destruction and degradation of natural ecosystems and increased the inputs or organic matter and nutrients to water, and enhanced the emissions of greenhouse gases by these production systems (Martinez-Porchas et al. 2012).
13. Inland surface waters and water bodies/ freshwater		Ongoing pollution, land use changes in watersheds, and establishment of dams have degraded inland surface waters and water bodies and increased their emissions of greenhouse gases (Tranvik et al 2009; Smith et al. 2013). Large dam constructions for producing hydroelectrical energy, especially in the tropics, have increased CH_4 emissions by decomposition of submersed ecosystems (Fearnside et al. 2016)
14. Shelf ecosystems (neritic and intertidal zone, estuaries, mangroves)	Down	Mangrove forests being destroyed by coastal degradation and climate change, and this carbon sequestration declining (Heckbert et al. 2012)
15. Open ocean pelagic systems	Up	Possible expanded range of nitrogen-fixing phytoplankton with warming of the upper ocean; likely to be increased net primary productivity implying enhanced carbon sequestration however this is uncertain.

16. Deep-sea	Up	Possible expanded range of nitrogen-fixing phytoplankton with warming of the upper ocean; likely to be increased net primary productivity implying enhanced carbon sequestration; Net primary productivity is likely to increase at least in the Arctic and Antarctic

4.4. Impacts on good quality of life

4.4.1. Different types of value

4.4.1.1. What is the NCP contribution

Climate influences all different components of people's good quality of life, such as nutrition, economy, vulnerability to diseases and natural disasters, water supply, and identity, so its regulation by ecosystems plays an utmost role for human wellbeing. The contributions of ecosystems to climate regulation are perceived at different scales. For instance, the benefits of trees and parks in providing shading and fresher air in cities is easily perceived by people, whereas the benefits of tropical forest conservation to mitigate global climate changes is now well recognized. Quality of life is affected in different ways depending on the type of value considered. Climate change impacts are expected to be greater in health and agriculture, specially in Africa and Asia (OCDE 2015).

Health: Climate regulation controls the frequency, magnitude and location of extreme climatic events, like droughts, flooding, heat waves, and hurricanes, which have directly caused mortality, morbidity, and health problems to people in all global regions, as well indirect health problems associated to reduced food supply and restrictions in drinking water supply (Haines et al. 2006; McMichael et al 2006). Acute weather events, which increasing severity and frequency have been associated to climate changes (Berry 2006), are directly linked to health, like in the cases of thermal stress caused by heatwaves and physical hazards to people caused by floods, storms, and fires (McMichael et al., 2006). The increased severity and frequency of sub-acute adverse weather events are also related to the dissemination of infectious diseases, especially those that are vector-borne. The World Health Organization estimates that over 150,000 people per year have died in the last 30 years because of human-induced changes in temperature and precipitation (Patz et al. 2005). Climate change may also affect mental health, by causing trauma in people and indirect impacts resulted from the impairment of the physical health of vulnerable people and of community wellbeing (Berry et al. 2009).

Economic: Extreme climatic events caused by climate malfunctioning has multiple impacts in economy, including the destruction and deterioration of infrastructure (e.g., destruction of dam, bridges, and buildings), negative consequences for services (e.g., flight delays, urban transportation), but also and food availability due to effects on crop productivity (Wheeler and von Braun 2013) and fisheries (Sumaila et al., 2011). There are several social costs associated to climate changes, like those caused by health problems (Bosello et al. 2006), and increased costs to provide environmental comfort to people. Finally, all economic activities are dependent someway on climate and are mostly negatively affect by its anthropogenic modification. Evident examples of climate-dependent human activities includes agriculture, hydro-energy, and natural resources management (Stern, 2013). For example, warming caused by climate change have caused an annual loss of $5 billion per year of barley, maize and wheat production (Lobell and Field 2007).

Socio-cultural (Learning, experience, and identity): Much of the experience and identities of people in linked to climatic conditions and the ancient connection of societies activities with Nature cycles. Climate change may disrupt this connection and force human migration and modifications in cultural practices and events, which may compromise the spiritual and psychological experiences, sense of home, and cultural identity. Extreme climatic events may also destroy sacred places and other locations of religious or cultural importance to people. Climate change has also been one of the major examples of the negative, widespread impacts of anthropogenic activities on Nature, and how it impacts human wellbeing. It has provided an important learning experience to humans and is now disseminated in society.

4.4.1.2. How do we measure that value/contribution?

The contributions of climate regulation by Nature on people's good quality of life have been measured according to different metrics, in spite of the limitations to distinguish between the direct contributions of ecosystems and those of other climate components on the benefits for human wellbeing. The measurements have been mostly based on the economic losses resulted from extreme climate events and less intense alterations in climatic patterns, like those affecting agriculture production and diseases incidence in urban regions. Non-material impacts in human thermal comfort and psychological perceptions, for instance, are more challenging to quantify, but also important to measure.

Health: The health benefits of climate regulation can be measured according to the incidence of human diseases promoted by climate change, the number of deaths and people with any kind of illness caused by natural disasters associated to climate change, as well those associated to chronic health problems resulted, for instance, from the intensification of pollution problems in cities because of longer dry seasons (Confalonieri et al. 2007). Other ways of measuring the benefits of climate regulation to human health is through the monitoring undernourishment and associated diseases cases by reduced food availability resulted from extreme climate events (Wheeler and von Braun 2013). Psychological impacts can also be measured by assessing acute anxiety disorders, elevated rates of violence and aggression, rates of chronic mood disorders, and suicide ideation and attempts (Berry 2009).

Economic: The aforementioned impacts in health can also be quantified in economic terms, accounting for problems like the loss of labor productivity and additional costs with health care (Bosello et al. 2006). In addition, extreme climatic events and natural disasters have caused well-known impacts on infrastructure (Wilbanks et al. 2007). The negative economic impacts in the production of agriculture, fisheries, hydro-energy, and products directly exploited from native ecosystems can also be measured to assess the impacts of depleting the contribution of ecosystems to regulate climate. Quantitative estimates of the economic damages of climate change usually are based on aggregate relationships linking average temperature change to loss in gross domestic product (GDP). However, there is a clear need for further detail in the regional and sectoral dimensions of impact assessments to design and prioritize adaptation strategies (Ciscar et al. 2010).

Socio-cultural (Learning, experience, and identity): non-material impacts of climate change to people can be measured by several methods employed in social sciences, like questionnaires, interviews, and direct observations.

4.4.1.3. Substitutability

Humans have mainly seek to mitigate climate changes through the reduction of greenhouse gases emissions and removal of these gases from the atmosphere. Although natural climate solutions, through which the contribution of Nature to regulate climate is enhanced through human interventions, provide unique cost-effective opportunities to mitigate climate (Griscom et al. 2017), other climate engineering technologies have been suggested to substitute, or complement, the role of ecosystems. Examples include ocean fertilization to increase marine primary productivity and carbon sequestration (Markus and Ginzky 2011), use of technologies to direct removal of atmospheric CO_2, artificial creation of biochar, and enhanced weathering. The scalability of these technologies is yet uncertain and the risks to biodiversity and threats to natural systems may prevent the use non-natural climate engineering approaches as substitutes for the role performed by ecosystems.

4.4.2. Indicators of NCP impact

4.4.2.1. Indicators by value

Value type	Indicator/ Proxy	Rationale/ justification for why we this indicator/ proxy was selected	Data set	Scale of Measure – space	Scale of measure - time
Health	Number of deaths caused by extreme climatic events	Climate change has increased the frequency and magnitude of extreme climate events, which has caused natural disasters and deaths	https://www.ncdc.noaa.gov/climate-information/extreme-events For flood: http://www.dartmouth.edu/%7Efloods/Archives/index.html	USA	
	Food security and climate change	Food production braks caused by climate change	http://climate-adapt.eea.europa.eu/metadata/publications/ipcc-fifth-assessment-report-wgii-chapter-7-food-security-and-food-production-systems		
	Number of undernourished people	Threats to food security caused by extreme droughts associate to climate change	http://www.fao.org/faostat/en/#data/QC	Country	Year; 1961-2013
Economic	Crop production breaks caused by climate change	Global warming have created unfavorable conditions for growing food crops	Lobell and Field, 2007 (barley, maize and wheat)	Global	1981-2002
	Economic impacts of climate change on specific aspects of regional economic activity, such as labour productivity, the supply of production factors such as capital, and	Modelled impacts of climate change for agriculture, coastal zones, some extreme events, health and energy	http://www.oecd.org/env/the-economic-consequences-of-climate-change-9789264235410-en.htm		2015-2060

	changes in the structure of demand				

4.4.2.2. Trends by user group

User Group	Direction of arrow	Rationale/ justification for why you think this trend is happening
Universal	down	In general, associated to the destruction and degradation of natural ecosystems and their consequent potential to sequester and stock carbon
Subsistence and small scale harvesting	down	Subsistence and small-scale harvesting practices may be disrupted by climate change, which may cause abrupt declines in fishing stocks, mortality of commercially valuable native species, and drought-induced degradation of pastures and crop breaks
Commercial harvesting	down	The same as above, but the higher access to resources and technology, like irrigation, fertilization, and pesticides, may increase the capacity of this user group to face changes in production systems
Industrial, commercial, and service professional	down	Higher costs with energy and infrastructure
Urban	down	Increased premature mortality and health problems, energy and infrastructure costs, reduced food and water supply
Rural	down	The same as above, plus reduced revenues from agriculture production

	Impact of Output of Joint Production on Good Quality of Life by Major Social Group
Indicator	Negative impacts on economy, health, and socio-cultural issues
Trend During the last 50 years: 2 = Major increase (>20%) 1 = Increase (5% to 20%) 0 = No change (-5% to 5%) -1 = Decrease (-20% to -5%) -2 = Major decrease (< -20%)	-2 (climate change has increased the frequency and magnitude of extreme climate events and historical climatic conditions in different regions, which has caused natural disasters and deaths, and proliferation of diseases; has caused agricultural production breaks, and causing all different types of negative consequences on economic development)
Variance across social groups 3 = opposite trends for different groups 2 = same directional trends for different groups but contrasting magnitudes 1 = similar trends for all social groups	3 (overall, climate change has compromised economies, people's health and socio-cultural issues for most social groups, through different processes depending on the group considered. However, climate change has favored agriculture production in high latitudes).
Spatial variance 3 = opposite trends in different regions 2 = same directional trends in different regions but of contrasting magnitude 1 = similar trends all over the world	3 (climate change has negatively affected people's quality of life in most global regions, especially in coastline, islands and drylands, but has improved the conditions for agricultural production in high latitudes).

Degree of certainty 4 = **Well established**: Robust quantity and quality of evidence & High level of agreement 3 = **Established but incomplete**: Low quantity and quality of evidence & High level of agreement 2 = **Unresolved**: Robust quantity and quality of evidence & Low level of agreement 1 = **Inconclusive**: Low quantity and quality of evidence & Low level of agreement	4 (there are numerous specific papers, synthesis, and IPCC reports describing the negative impacts of climate change in the good quality of life)
Two to five most important papers supporting the reported trend	IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

4.5. Summary

4.5.1. Status

Nature plays an utmost role in regulating climate by stocking large amounts of carbon in the biomass, soil and water of ecosystems, recycling water by maximizing through vegetation the flow of water from soils to the atmosphere, and modifying irradiation reflectance from Earth by favoring cloud formation through biogenic compounds and altering land albedo, can effectively contribute to mitigate climate changes if protected from degradation and restored. The increase in the global leaf area index evidences that the potential of terrestrial ecosystems to sequester carbon and increase albedo is increasing, in spite of the still high destruction of the ecosystems with the highest carbon stocks per unit of area – tropical forests. The increasing global demands for fiber, food and fuel have threatened the contribution of Nature to regulate climate due to the conversion of carbon-rich, high evapotranspiration ecosystems contributing to sequester carbon and recycle moisture to agricultural areas, which usually have a reduced potential than natural ecosystems to regulate climate and has contributed to climate change by increasing emissions of greenhouse gases by expanding meat production and fossil fuel use.

4.5.2. Similarities and differences across Units of Analysis and across User Groups

Tropical and subtropical dry and humid forests, Tropical and subtropical savannahs and grasslands, and Wetlands are the inland ecosystems with higher declines in their capacity to regulate climate due to their ongoing destruction and degradation by human activities; cultivated areas will also have their contribution reduced due to increased production of meat and use of fossil fuels in farming, while coastal areas and oceans (UoA 14, 15, 16 and 17) will have their contribution impaired by acidification. Cryosphere may also have their contribution impaired because of their ongoing melting. On the other hand, forest transitions have transformed Temperate and boreal forests and woodlands into large carbon sinks due to net gains in forest cover. Subsistence and small-scale harvesting, and Commercial harvesting are the user groups receiving the higher impacts of the lower levels of climate regulation by ecosystems, due to the potential disruption of subsistence and commercial harvesting by climate change, which may cause abrupt declines in fishing stocks, mortality of commercially valuable native species, and drought-induced degradation of pastures and crop breaks.

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4.7. Search methodology

Database: Web of Knowledge.

Search strings:

(1) ("climate" OR emission*) AND ("greenhouse gas*" OR "biological carbon" OR methane OR "surface roughness" OR "long-wave radiation" OR evapotranspiration OR "moisture-recycling" OR "biogenic volatile organic compound" OR "BVOC" OR aerosol OR "sulphur oxide" OR "nitrogen oxide" OR nox)

(2) ("climate" OR emission*) AND ("greenhouse gas*" OR "biological carbon" OR methane OR "surface roughness" OR "long-wave radiation" OR evapotranspiration OR "moisture-recycling" OR "biogenic volatile organic compound" OR "BVOC" OR aerosol OR "sulphur oxide" OR "nitrogen oxide" OR nox) AND (review OR synthesis OR "meta-analysis" OR "state of art" OR overview)

(3) climate AND ("greenhouse gas*" OR "biological carbon" OR methane OR "surface roughness" OR "long-wave radiation" OR evapotranspiration OR "moisture-recycling" OR "biogenic volatile organic compound" OR "bvoc" OR aerosol OR "sulphur oxide" OR "nitrogen oxide" OR nox)

(4) climate AND ("greenhouse gas*" OR "biological carbon" OR methane OR "surface roughness" OR "long-wave radiation" OR evapotranspiration OR "moisture-recycling" OR "biogenic volatile organic compound" OR "bvoc" OR aerosol OR "sulphur oxide" OR "nitrogen oxide" OR nox) AND (review OR synthesis OR "meta-analysis" OR "state of art" OR overview)

Total hits for each string

(1) 122,548

(2) 8,655

(3) 40,909

(4) 3,382

Even some strings included keywords about reviews; we also manually excluded proceeding and data papers, book reviews and book chapters that emerged. We did not consider papers evaluating: methodological procedures to measure compounds, models, simulations, mitigation (e.g. biofuels, renewable energies, and energy technologies), political ecology of climate change and regulation, and implications of climate change (e.g. on health, industries and others). After reviewing abstracts, we selected a total of 97 papers. We finally included 38

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5. NCP 5 - Regulation of ocean pH/acidification

Prepared by Ute Jacob and Lynne Shannon

5.1. IPBES Definition:

Regulation, by photosynthetic organisms (on land or in water), of atmospheric CO_2 concentrations and so seawater pH, which affects associated calcification processes by many marine organisms important to humans (such as corals and shellfish).

5.2. Why is this NCP important?

5.2.1. What is the big environmental issue this pertains to?

Ocean acidification inhibits calcification processes critical to many marine organisms important to humans and ocean food chains. Increases in atmospheric CO2 drive this.

The addition of CO_2 to the ocean is already causing a rise in acidity, which will have an increasing negative effect on the structure and functioning of marine ecosystems (Jeffree 2009). Ocean acidification is impacting marine ecosystems through a variety of pathways. Differing sensitivities in ecophysiological performance traits will result in ecological winners and losers, as well as temporal and spatial shifts in trophic interactions between species (e.g., shifts in the timing of zooplankton development relative to food availability; Pörtner and Farell 2008), leading to changes in food web interactions. There may also be changes in habitat quality and in other ecological processes. Many of the physiological changes from ocean acidification are expected to affect important functional groups of species. Such changes will most likely lead to cascading impacts in the composition, structure, and function of marine ecosystems.

The resulting acidification of the ocean is occurring at different rates across marine ecosystems, but is generally decreasing the levels of calcium carbonate dissolved in seawater, thus lowering the availability of carbonate ions, which are needed for the formation by marine species of shells and skeletons.

Ocean acidification will impact all areas of the ocean, from the deep sea to coastal estuaries (Feely *et al.* 2010), with potentially wide-ranging impacts on marine ecosystem structure and functioning (Doney *et al.* 2009). The average pH of ocean surface waters has decreased by about 0.1 unit—from about 8.2 to 8.1—since the beginning of the industrial revolution, with model projections showing an additional 0.2-0.3 drop by the end of the century (Caldeira and Wicket 2003). A meta-analysis conducted by Kroeker *et al.* (2013) revealed reductions in survival, calcification, growth, development, and abundance in response to ocean acidification across a broad range of marine organisms. This suggests that the effect of ocean acidification will be widespread across marine ecosystems. Especially heavily calcified organisms, including calcified algae, corals, mollusks, and the larval stages of echinoderms, are the most negatively impacted, which will lead to feed back loops across the entire ecosystem structure.

Ocean acidification is causing rapid reductions in calcium carbonate availability with implications for many marine organisms. It is likely that although some species will be tolerant, it will impact many marine organisms and ecosystem processes, including composition of communities and food webs and nature's benefits to people. For example, shellfish exhibit a negative response to ocean acidification, which threatens the economic benefit of this seafood. In addition to this negative effect on shellfish provisioning, ocean acidification also negatively impacts the aesthetic benefits of coral reefs and the associated ecotourism opportunities. Marine ecosystems under the stress of ocean acidification may become less resilient to other drivers of change, including extreme weather, nutrient pollution, or overfishing, becoming less able to recover from these types of challenges.

5.2.2. How does this NCP play a role?

- Ocean acidification will continue at a rate never encountered in the past 55 Myr
- Future ocean acidification depends on emission pathways
- The legacy of historical fossil fuel emissions on ocean acidification will be felt for centuries
- Ocean acidification will adversely affect calcification
- Ocean acidification will change the composition of marine communities
- Ocean acidification will impact food webs and higher trophic levels
- Ocean acidification will have biogeochemical consequences at the global scale

5.3. Co- production

5.3.1. How is this NCP produced?

The future magnitude of ocean acidification will be very closely linked to atmospheric CO_2; it will, therefore, depend on the success of emission reduction. Increasing CO_2 concentrations are expected to enhance rather than decrease the growth of photosynthetic organisms and the production of organic matter in the ocean and therefore enhance pH regulation. But this effect is generally modest and will most likely not balance the increasing CO_2 concentrations (Williamson & Turley 2012).

Dense seaweed beds and kelp forests represent productivity hot-spots with associated high pH when photosynthesis reduces CO_2 concentrations (Duarte 2017). They may play a role in protecting calcifiers from projected ocean acidification.
Seaweed farms are similarly reported to support high marine biodiversity. 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) depend also on currents and increases where the farms are located in coastal environments.

With warming of the upper ocean, the geographical range of nitrogen-fixing phytoplankton is likely to expand, so that net primary productivity may increase but the phytoplankton community may be comprised of a larger proportion of small-celled phytoplankton (Morán *et al.*, 2010, Duarte 2017).

<u>*Summary of how this NCP is produced*</u>:

- ***Direct***: Sequestering of CO_2 by aquatic vegetation reduces ocean acidification locally
- ***Direct***: Conversion of bicarbonate to carbonate by marine organisms to build shells produces hydrogen ions, increasing ocean acidification locally.

5.3.2. How is co production of this NCP measured?

Measurements may be direct (observed, *in situ*) or modelled:

- Direct measures of regulation of ocean acidification include: diurnal changes in ocean pH linked to plants; plant biomass (CO_2 uptake); carbonate formation and hydrogen ion release (estimate based on number of shells)
- Model-based estimates of impacts of regulation of ocean acidification on marine biota carbon sequestration

Atmospheric carbon dioxide (CO_2) concentration has increased by 42% since the onset of the industrial revolution due to emissions from fossil fuel burning, cement production and land-use change. Declines in surface ocean pH due to ocean acidification are already detectable and accelerating. Measurements gathered at biogeochemical time-series sites around the world reveal similar decreasing trends in ocean pH (reductions between 0.0015 and 0.0024 pH units per year), but datasets are only available for the last few decades. Under most emission scenarios, Earth system models project an acceleration in acidification at least until mid-century. When forced by the latest scenarios from work of IPCC, simulations indicated that reductions in surface pH will depend almost solely on the atmospheric CO_2 concentration, and thus on global efforts to reduce atmospheric CO_2. Enhanced ocean CO_2 uptake alters the marine carbonate system, which controls seawater acidity. As CO_2 dissolves in seawater it forms carbonic acid (H_2CO_3), a weak acid that dissociates into bicarbonate (HCO_3^-) and hydrogen ions (H+). Increased H+ means increased acidity (lower pH). The rate of the ocean's acidification is slowed by the presence of CO_3^{2-}, which binds up most of the newly formed H+, forming bicarbonate. However, that buffering reaction consumes CO_3^{2-}, reducing the chemical capacity of the near-surface ocean to take up more CO_2. Currently, that capacity is only 70% of that at the start of the industrial era. It is anticipated that this buffering capacity will be further reduced to only 20% by the end of the century.

Indicators of pH regulation by the ocean include the following:

- pH: (lower pH = more acidic)
- Air–sea and sediment–water fluxes of carbon and CO_2 (modelled or empirically determined); units: mg $C.m^{-2}.d^{-1}$, mg $CO_2.m^{-2}.d^{-1}$
- Levels of carbon in different components of the marine ecosystem (modelled or empirically determined carbon levels: biomass of carbon (units: $g.m^{-2}$); dissolved organic or inorganic carbon (units: mg $C.m^{-3}$); suspended organic or inorganic carbon (units: mg $C.m^{-3}$);
- Net primary production (units: $mgC.m^{-2}.day^{-1}$).;
- Atmospheric levels of CO2.

5.3.3. Links to other NCPS

NCP4 – climate – The regulation of ocean acidification is directly driven by: atmospheric CO_2; NCPs that promote vegetation growth and therefore reduction in atmospheric CO_2 reduce ocean acidification:

Local impacts to ecosystem caused by coastal source water:
NCP6 – water quantity
NCP7 – water quality

Production of these NCPs may impact atmospheric CO_2/NCP4-climate; marine production of these NCPs will likely be affected by the regulation of ocean acidification:
NCP9 – hazards (coastal protection)

NCP11 – energy
NCP12 – food -Shellfish availability may decline under ocean acidification as a result of the uptake of atmospheric CO_2 (Bőhnke-Henrichs *et al.* 2013)
NCP13 – materials
NCP14 – medicine

Regulation of ocean acidification affects marine habitats that may be important for:
NCP15 – learning
NCP16 – experiences
NCP17 - identities

5.3.4. Indicators of NCP joint production

NCP	Production Function	Indicator/ Proxy	Rationale/ justification for why this indicator/ proxy was selected	Data set	Scale of Measure – space	Scale of measure - time
	Plants absorb CO_2 thereby offsetting ocean acidification locally at least	Extent of marine vegetation, e.g. net primary production and seaweed aquaculture	*Measure of regulation potential of ocean acidification through absorption of CO_2/ carbon sequestration*	http://www.science.oregonstate.edu/ocean.productivity/index World Ocean Assessment Chapter 6 Figure 1	Global	2003 onwards
	Calcification releases H+	Extent of marine calcification	*Mitigation measure*			

5.3.5. Trends in Co Production

5.3.5.1. General (across all units of analysis)

Ocean acidification represents a threat to marine species worldwide, and forecasting the ecological impacts of acidification is a high priority for science, management, and policy. A major challenge of the current century is to ensure a sustainable provision of essential NCPs. Whilst there may be local actions to limit acidification from local sources, the root cause of ocean acidification, namely atmospheric CO_2 emissions, is a global issue requiring global action.
Global oceans absorb significant portions of CO_2 emissions from human activities, equivalent to ~93% of the extra energy arising from anthropogenic greenhouse gas emissions, resulting in an increase in average global sea surface temperatures that approaches 1°C (0.89 °C over the period 1901–2012; IPCC, 2013). The ocean has also taken up ~30% of anthropogenic carbon dioxide that has been released into the atmosphere, decreasing ocean pH, and fundamentally changing ocean carbonate chemistry in all regions (IPCC, 2013). Ocean acidification is a rapidly increasing global problem that intensifies with continued CO_2 emissions and has the potential to change the structure and function of marine ecosystems and alter availability of various NCPs. Despite decades of empirical research into how individual stressors of global change (i.e., temperature, CO_2, dissolved oxygen levels) affect marine organisms and alter the structure and function of marine ecosystems, we still know little about the synergetic effects of these stressors and their impact on marine biodiversity and ecosystem services (Kelly *et al.* 2011; Hoegh-Guldberg *et al.*, 2014; Pörtner *et al.*, 2014).

Mitigation measures:

Promoting seaweed aquaculture

Seaweed aquaculture might function as a tool for climate change mitigation and adaptation. The growing seaweed aquaculture industry is already delivering these benefits, which have not been properly accounted for nor have been credited to seaweed farmers. Because of the very low investment required to set up seaweed aquaculture farms, seaweed aquaculture is a particularly sound strategy for coastal developing nations to contribute to climate change mitigation while protecting their shoreline and marine ecosystems from some of the effects of climate change, such as ocean acidification and ocean de-oxygenation. Constraints for the expansion of the climate mitigation and adaptation benefits associated with seaweed aquaculture are multiple. In the case of China, the main challenges are competition for suitable space with other uses/users and the maintenance of a sufficient profit margin to continue to engage farmers. More generically, the constraints involve physical constraints, such as the availability of suitable areas; regulatory constraints, such as the requirements for concessions for seaweed aquaculture; marine spatial planning constraints, such as competition for space with other marine-based activities; and market constraints, such as the existence of demand for seaweed aquaculture products, necessary to maintain a profit margin that may motivate prospective farmers to engage. Promoting seaweed aquaculture as a component of climate change mitigation and adaptation strategies requires that all four dimensions of the social-ecological system that supports seaweed aquaculture (Broitman *et al.*, 2017) be addressed: (1) biological productivity to enhance carbon capture, (2) environment constraints to the expansion of seaweed aquaculture, (3) policy tools that enable seaweed aquaculture, and (4) manage societal preferences and markets demands for seaweed products. Maintaining a market price that encourages seaweed farmers to engage and implement design improvements to maximize climate services delivered by the farm, requires that markets diversify to increase the demand for seaweed products. Subsidizing farmers, either directly or indirectly through tax abatement, for farms credited as blue carbon seaweed farms may further increase engagement with this strategy. While the contribution of seaweed aquaculture to climate change mitigation and adaptation will remain globally modest, it may be substantial in developing coastal nations and will provide add-on value to the societal benefits derived from seaweed aquaculture.

Reducing Marine Pollution
In areas with high levels of local pollution (e.g., bays and estuaries), mitigation of these local sources of pollution may help offset some of the local pH change. However, local-scale mitigating is likely to have only local-scale effects.,

Summary of NCP trends:
- ***Trend***: **declining** due to global warming and continuing CO_2 emissions
- ***Spatial variance***: **variable**, with some hotspots (Mangroves, marshes, seagrass)
- ***Degree of certainty***: **not certain**
-

	Outputs	**Potential Nature's Contributions**
Indicator	Air–sea and sediment–water fluxes of carbon and CO2 Extent of marine calcification	Extent of marine vegetation: net primary production seaweed aquaculture

Trend During the last 50 years: 2 = Major increase (>20%) 1 = Increase (5% to 20%) 0 = No change (-5% to 5%) -1 = Decrease (-20% to -5%) -2 = Major decrease (< -20%)	-1 (fluxes have increased therefore ability of the ocean to regulate acidification has declined) -2	1 1
Spatial variance 3 = opposite trends in different regions 2 = same directional trends in different regions but of contrasting magnitude 1 = similar trends all over the world	2 (variable with some hotspots) 1	3 2 Physical impacts associated with farming structures and farm operations, alteration of coastal habitat diminishes or changes the regulation capacity of ocean acidification
Degree of certainty 4 = Well established: Robust quantity and quality of evidence & High level of agreement 3 = Established but incomplete: Low quantity and quality of evidence & High level of agreement 2 = Unresolved: Robust quantity and quality of evidence & Low level of agreement 1 = Inconclusive: Low quantity and quality of evidence & Low level of agreement	4 3	2 2

5.3.5.2. By Units of Analysis

12. Aquaculture areas LUC? Management: More intensive		Physical impacts associated with aquaculture structures and operations, and alteration of coastal habitat diminishes or changes the regulation capacity of ocean acidification
14. Shelf ecosystems (neritic and intertidal zone, estuaries, mangroves) LUC ?		Dense seaweed beds and kelp forests represent productivity hot-spots with associated high pH when photosynthesis reduces CO_2 concentrations (Duarte 2017). They may play a role in protecting calcifiers from projected ocean acidification.
15. Open ocean pelagic systems		Open pelagic systems show CO_2 values three times higher than the current global mean (1200 versus ~400 µatm; Harris *et al.* 2013), and conditions corrosive to calcified marine organisms have increased in frequency, severity, duration, and spatial extent due to anthropogenic CO_2 rise. However, increase predicted primary productivity with global warming will help to buffer ocean acidification.
16. Deep-sea		Acidification of the deep sea will occur more slowly than in surface seawater. But its ecological effects may nonetheless be severe because of the assumed greater sensitivity of the deep-sea biodiversity.
17. Coastal areas intensively managed and multiply used by people		Coastal areas intensively used by people are impacted by freshwater inputs, pollutants, and soil erosion, which lead to an increased

		acidification of coastal waters at substantially higher rates than by atmospheric CO2 alone. These non-atmospheric inputs can't be buffered.

5.4. Impacts on good quality of life

5.4.1. Different types of value

5.4.1.1. What is the NCP contribution

The ocean provides food and livelihoods for millions of people and subsequently contributes to good quality of life. Its coastal ecosystems, such as coral reefs, mangroves, salt marshes, seagrass and kelp beds, protect shorelines and also store carbon. The substantial alteration in basic ocean chemistry associated with future ocean acidification is likely to have wide implications for life in the ocean, with socio-economic consequences, including for food security.

For example, 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 CO2 emissions scenarios (Brander et al. 2009) 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).

Ocean acidification is especially problematic for corals and shellfish, because it prevents them from properly developing their skeletons and shells. Shrinking coral reefs could dent eco-tourism revenue in some coastal areas.

Polar, subpolar, and deep-sea ecosystems and shallow productive seas including those associated with upwelling of CO_2-rich seawater are also at risk as ocean acidification will be most severe there. Ocean acidification is not the only climate related threat to the oceans, with ocean warming and oxygen loss also of great concern.

In summary, world fisheries already face multiple challenges but some are now further subject to the combined global scale stressors of ocean acidification, warming and de-oxygenation.

5.4.1.2. How do we measure that value/contribution?

Methods of measuring this NCP impact

- MUCH easier to find value of shellfish landed then to find impact of regulation of ocean acidification on shellfish
- Biophysical measures – amount of food generated
- Health measures – nutritional impact
- Economic methods- value of food created, income generated from food products, travel cost studies of recreation
- Sociological methods – interviews about importance of various organisms to place, identity, learning

5.4.1.3. Substitutability

- Final replacement – reduce CO_2 emissions into the atmosphere so that regulation of ocean acidification is unnecessary

- Process equivalent: Geo-engineering approaches to reducing CO_2 in seawater, changing PH of seawater

- Climate engineering: technology may partially substitute ocean-based carbon capture and storage, although nowhere near the scale that the ocean provides for climate regulation.

- Sequestering carbon on the ocean floor by fertilizing certain ocean regions with iron will lead to rises in primary productivity (Pollard *et al.* 2009). The resulting phytoplankton blooms produce more carbon-containing molecules which then travel through the food web (carbon flux) and sink down to be sequestered on the sea floor.

- The addition of powdered limestone to ocean water will lead to a reaction with CO_2 and form bicarbonate (Rau and Caldiera 1999; Harvey 2008). This would neutralize the acidity of the added carbon dioxide, as well as push the oceanic carbon equation towards carbonic acid and allow for more calcium carbonate to stay undissolved in the shells of calcifying species.

Important caveat: Addition of limestone or iron fertilization might prove to replace or enhance this NCP but will have profound effects on ocean biochemistry and biology.

Human Mitigation measures
1. Ensure that precipitation runoff and associated pollutants (which can increase acidification) are monitored and limited
2. Control coastal erosion as a classic function by reducing nutrient and sediment loading of water and protecting the physical integrity of the habitat itself.
3. Manage land-use changes through local and regional planning, zoning, and permitting policies can reduce direct and indirect (e.g., deforestation) CO_2 emissions, runoff, and other threats
4. Promote seaweed aquaculture (see section 3.3.1)
5. Reduce atmospheric CO_2.

5.4.1.4. Status and Trends in impact (value)

The oceans have absorbed about 28 percent of the carbon dioxide produced by humans globally over the last 250 years (Sabine *et al.* 2004). This increased carbon dioxide makes the oceans more acidic (reduces the pH), and carbon dioxide emissions are still rising. Globally, pH has declined about 0.1 pH units, or an increase in acidity of about 30 percent (Feely *et al.* 2009).

In marine ecosystems, marshes, mangroves, and seagrass meadows take up CO_2 from seawater. These marine environments can store a large amount of carbon and may help offset ocean acidification locally. Carbon stored in coastal environments like marshes, mangroves and seagrass meadows is called “blue carbon”. This “blue carbon” is locked into organic matter that can be preserved for a long time. Current research is continuing on how much carbon these systems can store and especially mangroves and seagrass beds are natural hot spots for carbon sequestration. “Blue carbon” may represent a way of offsetting some amount of ocean acidification locally. There are initiatives to protect ‘blue carbon’ stores in coastal ecosystems such as tidal salt marshes, mangroves and seagrass meadows, which store large amounts of organic carbon (Kennedy *et al.* 2010). The current knowledge of these ‘blue carbon’ stores are less advanced than for terrestrial systems (Duarte *et al.* 2011) but C stores of mangroves and seagrass meadows have been estimated at 1,023 MgC ha^{-1}(Donato *et al.* 2011) and 139.7 MgC ha^{-1}, (Fourqurean *et al.* 2012), and the carbon burial in seagrass meadows is between 48 and 112 Tg yr^{-1}.

The future magnitude of ocean acidification as well as its mitigation will be very closely linked to atmospheric CO_2; it will depend on the success of emission reduction, and could also be constrained by geo-engineering based on most CDR techniques (Joos *et al.* 2011). Improving our understanding of direct temperature effects in marine ecosystems (e.g., via metabolic processes) will improve our predictions (modelled) of likely changes and spatial variability in marine primary production (Taucher and Oschlies 2011), which will have implications for the ocean's ability to regulate ocean acidification.

5.4.2. Indicators of NCP impact

5.4.2.1. Indicators by value

Value type	**Indicator/ Proxy**	**Rationale/ justification for why we this indicator/ proxy was selected**	**Data set**	**Scale of Measure – space**	**Scale of measure - time**
Value type A		*There's good evidence? It's the easiest? We have the data? The data time series is long enough?*	URL, citation		
Food		Changes in food (especially shellfish production) due to regulation of ocean acidification	FAO database	global	annual
Income					
Coastal Protection	Extent of Coral Reefs	Focusing on reefs adjacent to human settlements.		km²	Annual-decadal
Recreation	Extent of Coral Reefs	Focusing on reefs with high visitation rates or possibility		km²	Annual-decadal
Identity					

5.4.2.2. Trends by user group

	Impact of Output of Joint Production on Good Quality of Life by Major Social Group
Indicator	Change in seafood availability due to regulation of ocean acidification Extent of coral reefs -impacts on the well-being of coastal communities Extent of coral reefs -impacts on the ecotourism industry
Trend During the last 50 years: 2 = Major increase (>20%) 1 = Increase (5% to 20%) 0 = No change (-5% to 5%) -1 = Decrease (-20% to -5%) -2 = Major decrease (< -20%)	-2 Shell fish availability has declined under ocean acidification as a result of the uptake of atmospheric CO_2 (Bőhnke-Henrichs *et al.* 2013) -2 Tropical coral reef ecosystems provide food, income, and coastal protection for around 500 million people throughout tropical coastal zones. -2 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.* 2009).
Variance across user groups 3 = opposite trends for different groups 2 = same directional trends for different groups but contrasting magnitudes 1 = similar trends for all social groups	2 2 2
Spatial variance 3 = opposite trends in different regions 2 = same directional trends in different regions but of contrasting magnitude 1 = similar trends all over the world	1 1 1

Degree of certainty 4 = **Well established**: Robust quantity and quality of evidence & High level of agreement 3 = **Established but incomplete**: Low quantity and quality of evidence & High level of agreement 2 = **Unresolved**: Robust quantity and quality of evidence & Low level of agreement 1 = **Inconclusive**: Low quantity and quality of evidence & Low level of agreement	3 3 3
Two to five most important papers supporting the reported trend	Bőhnke-Henrichs *et al.* 2013 Brander *et al.* 2009

5.5. Summary

5.5.1. Status

Ocean acidification, which affects the carbonate chemistry of the ocean, is directly caused by greater atmospheric emissions of carbon dioxide (CO_2). These emissions have increased over the last 200 years, primarily due to intensified industrialisation and agriculture resulting in greater burning of fossil fuels, cement manufacturing and land use change. Ocean acidification is a rapidly emerging issue with many nations starting to invest in research into the potential future impacts on organisms, ecosystems and food providing products. Ocean acidification is closely linked with climate change, as they share the same driver, the increasing atmospheric CO_2 causing threats to the ecological health and biodiversity of the marine environment.
Regulation of ocean acidification requires rapid and substantial cuts to anthropogenic CO_2 emissions to the atmosphere and hence, oceanic CO_2 concentrations.

The understanding on the potential effects of ocean acidification on commercial marine resource species is still limited. There are many uncertainties relating to the scale of socioeconomic impacts of ocean acidification on marine resources and food security. Important tasks and trends of this NCP are to:

• Recognize the security, economic and cultural importance of those marine species and habitats that are currently exploited.
• Identify marine resource species that are more flexible to change and which may encroach on habitats and survive in altered conditions
• Assess the options for development of environmentally sustainable 'aquaculture' options using species that are resistant to lowered pH or can be kept in conditions of controlled pH

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6. NCP: 6: Regulation of Water Quantity, Timing, and Location

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6.1. IPBES Definition:

Regulation, by ecosystems, of the quantity, location and timing of the flow of surface and groundwater used for drinking, irrigation, transport, hydropower, and as the support of non-material contributions (NCP 15, 16, 17)

Regulation of flow to water-dependent natural habitats that in turn positively or negatively affect people downstream, including via flooding (wetlands including ponds, rivers, lakes, swamps)

Modifying groundwater levels, which can ameliorate dryland salinization in unirrigated landscapes

6.2. Why is it important?

6.2.1. What is the big environmental issue this pertains to?

Freshwater is critical for human wellbeing, and it is a limited resource distributed unevenly across the globe by natural and human-driven processes. Water scarcity is a problem for many people worldwide (Brauman et al. 2016).

6.2.2. How does this NCP play a role?

Abiotic factors, particularly the volume and intensity of rainfall, as well as atmospheric evaporative demand and soil structure, are primarily responsible for overall water availability and groundwater recharge (Kim and Jackson 2012) (Beck et al., 2013). However, by regulating the quantity, timing, and flow of water through a suite of ecosystem processes, nature does influence the availability of water and its usability by people (Brauman, Daily, Duarte and Mooney, 2007). Increasing water availability in dry periods and decreasing water availability in flood periods is particularly important to human quality of life.

6.3. (Co-) production

6.3.1. How is it produced?

Regulation of water quantity:

As plants grow and assimilate carbon, they transfer water from the soil to atmosphere in a process called transpiration. Water also evaporates directly from the vegetative canopy. Through these combined processes, called evapotranspiration (ET), ecosystems influence the transfer liquid water to the atmosphere; higher ET reduces water yield from a watershed (Brauman, et al., 2007).

The physical structure and physiology of vegetation affects ET. Tall stature and large leaf area increase ET, as do physiological characteristics such as low stomatal control and C3 photosynthetic pathways, which cause plants to transfer water during the most water-intensive periods of the day, and perennial and/or evergreen vegetation, which sustain water demand over the course of the year (Zhang, Dawes, and Walker 2001; Kelliher, Leuning, Raupach and Schulze, 1995; Le Maitre, Gush and Dzikiti, 2015; Brown, Zhang, McMahon, Western and Vertessy, 2005; Hultine and Bush 2011). Perhaps more importantly, ET is limited by water availability in many locations; in these cases, vegetation with deeper rooting depth, and therefore increased access to water, has higher ET (Le Maitre, et al., 2015). Whether an ecosystem change affects water quantity is largely related to whether the new and old ecosystems have different ET (Le Maitre, et al., 2015). Because ecosystem structure and density affect ET, ET is not constant over time (Shi et al., 2012) (Jackson et al., 2005). It can take several decades for the hydrologic effects of land cover changes to come to equilibrium or to return to pre-harvest levels of water yield (Brown, et al., 2005).

Ecosystems can also interact directly with the atmosphere to affect water quantity through mechanisms such as fog or cloud water interception (Katata 2014) and snow shading (Varhola, Coops, Weiler and Moore, 2010); this is likely to be strongly affected by ecosystem characteristics such as leaf area (Ponette-González et al., 2015). These type of land-atmosphere interactions are known in indigenous and local knowledge (ILK). The Hawaiian proverb “Hahai nō ka ua i ka ululāʻau” translates to the rain follows after the forest, for example, and guided past and current land management work to preserve forests to protect water resources (Fletcher, Boyd, Neal and Tice, 2010).

Though the processes of photosynthesis and respiration do, respectively, destroy and create water molecules, this represents a tiny fraction of water on earth (Holland, Lazar and McCaffrey, 1986), so we focus on the ways that ecosystems regulate the quantity of water that passes through them. Water that is evapotranspired cycles and falls as presciptiation; rainfall recycling is addressed in NCP 4 climate regulation.

<u>Regulation of water location and timing:</u>

Ecosystems reduce the speed of water flow by physically interrupting flow paths and influence the partitioning of water flow between the surface and subsurface by channeling and dispersing water flows and changing soil structure (Smith, Cox and Bracken, 2007; Brauman, et al., 2007). Water diverted from overland flow into the subsurface may reduce flood peaks and increase base flow (Brauman, et al., 2007). Water that infiltrates may not recharge aquifers if it is taken up by vegetation, which can aid water table management (Pannell and Ewing 2006). To lower a water table, evidence suggests that nearly ¾ of the recharge area must be reforested before a substantial impact is seen (Le Maitre, Scott and Colvin, 1999).

The plant canopy and leaf litter increase infiltration by protecting soil from the direct impact of water droplets, thereby reducing soil sealing (Le Maitre et al., 1999). On bare soils, sealing crusts form quickly (Dubreuil 1985). However, in some cases vegetation increases overland flow by creating sealing crusts with hydrophobic compounds produced by certain types of vegetation, most commonly evergreen trees with resins or aromatic oils but also some grasses and certain microorganisms (Doerr, Shakesby and Walsh, 2000).

Vegetation redistributes water on the land surface. Vegetated canopies channel water via stem flow to the soil at their base (Johnson & Lehmann 2006). Water repellency may lead to preferential infiltration around plants (Doerr, et al., 2000). Runoff frequently occurs in micro-rivulets between sparse vegetation in semi-arid regions and on pathways and compacted areas in more humid regions (Dubreuil 1985).

Plants create preferential flowpaths into the soil as roots physically move soil particles, creating macropores, and by adding organic matter that affects hydraulic conductivity; plants with taproots create macropores that increase infiltration, while plants with fine roots can fill macropores and decrease infiltration (Johnson and Lehmann 2006; Liu et al., 2015). Soil biota also influence infiltration by affecting the presence of plant litter and creating macropores (Bardgett et al., 2001). The role that vegetation plays in protecting the soil surface and creating soil structure is probably larger in arid regions than in humid sites (Thompson, Harman, Heine and Katul, 2010).

Soil compaction that occurs through the process of land use change or via management activities such as road building or grazing, is often in and of itself sufficient to substantially affect infiltration, making it difficult to attribute changes to the ecosystem itself (Price 2011). Several studies have suggested that roads and the location of timber harvest relative to roads have a larger impact on runoff generation than the extent of land use change (Croke and Hairsine 2006). Soil compaction due to cattle grazing also reduces infiltration (Trimble and Mendel 1995).

Wetlands and freshwater ecosystems also regulate water flow. By storing water and slowing its movement, floodplain wetlands generally reduce flow speed and flow peaks, although permanently saturated headwater wetlands may either reduce or augment flood flows (Kadykalo and Findlay 2016) (Bullock and Acreman 2003). Within waterways, vegetation reduces flow speed (Montakhab, Yusuf, Ghazali and Mohamed, 2012).

<u>*Summary of how this NCP is produced*</u>:

- ***Direct***: Evapotranspiration (ET) affects the quantity of liquid water available in the short term by transferring water to the atmosphere
- ***Direct***: Infiltration affects the movement of water from the surface into the subsurface, increasing groundwater for base flow or direct use
- ***Direct***: The speed of surface water flow is controlled by physical blockage of water flows on the ground surface and short-term storage of water in wetlands and inland waters

6.3.2. How is it measured?

Direct measurement of evapotranspiration is difficult because it is a gas flux; it is frequently measured using a water budget as a loss of liquid water or with an energy balance approach (Rana and Katerji 2000). Hybrid measured-modeled approaches are also sometimes used, as with remote sensing of evapotranspiration (Courault, Seguin and Olioso, 2005) or eddy flux measurements. The impact of a change in vegetation on water regulation can be estimated as the expected difference in evapotranspiration; this can be computed by comparing the behavior of similar watersheds with different land cover or by tracking the hydrologic response of a watershed after a change in land cover (Andréassian 2004). These methods are complicated by the need for extensive data over long periods of time in order to differentiate hydrologic response to land cover change from response to variations in rainfall. As a result, hydrologic models have been developed to simulate the behavior of rainfall in a watershed, taking into account climate, soils, and vegetation (Beven 2011; Singh and Woolhiser 2002). These models are often highly calibrated, however, and are frequently deployed for purposes other than for what they were designed, so they may not be as successful at predicting changes in water regulation as we would hope (Blöschl 2013; Garen and Moore 2005). Functionally, most models rely on standardized values for water regulation based on soil, slope, and vegetation (Garen and Moore 2005) (Renard, Foster, Weesies, McCool and Yoder, 1997) with parameter values that are calibrated to make model outputs match measured data. To assess the role of land use on water quantity regulation at large scales, calculations based on changes in ET have been used to model likely impacts of afforestation on downstream flows (Zomer, Trabucco, Bossio and Verchot, 2008; Trabucco, Zomer, Bossio, van Straaten and Verchot, 2008).

For changes in water timing and location, point measurements of infiltration can be taken in the field, and runoff generation relative to rainfall can also be measured directly (Soulsby et al., 2008). Field measurements are often limited in both space and time, however, so the models are used to scale up to watersheds. These models range from process-based models that attempt to represent fine-scale movement of water to statistical or water-balance models applied at the watershed scale (Singh and Woolhiser 2002) (Fox and Wilson 2010). Most watershed models need calibration with local runoff data, and when that does not exist they are generally parameterized using coefficients reflecting general performance of different vegetation types based on studies done in temperate locations (Renard et al., 1997).

6.3.3. Links to other NCPS

NCP 4 – regulation of climate - When ecosystems divert water from the liquid to vapor form via ET, this affects precipitation, a phenomenon called moisture recycling (Pielke et al., 2006).
NCP 7 – regulation of water quality – quality plays a key role in determining the usability of freshwater
NCP 8 – Soils – soil quality is critical to infiltration

NCP 9 - Natural Hazard impact reduction – floods
Because reduced infiltration and reduced water storage capacity in the soil increase runoff, deforestation could increase flood peaks. Reduced flood peaks have been demonstrated in small watersheds for small and medium peak flows, but there is no evidence for the effect of deforestation on large floods; no direct effect of deforestation has been seen for large watersheds, though land use change such as cropland drainage and increased siltation may increase flooding (van Dijk et al., 2009).

Water is integral to the production of:
NCP 11 - Energy
NCP 12 - food and feed
NCP 13- materials
NCP 14 – medicines

Cultural context is critical in the demand for water, so its value is a function of
NCP 15 – learning
NCP 16 – Physical and psychological experiences
NCP 17 - Identity

6.3.4. Indicators of NCP (co-) production

NCP	Production Function	Indicator/ Proxy	Rationale/ justification for why this indicator/ proxy was selected	Data set	Scale of Measure – space	Scale of measure - time
Water quantity	Change in ET	Land use change that causes a change in ET	Models of ET with different land cover types. Could use CGIAR in a pinch	NASA, MODIS Global Evapotranspiration Project (MOD 16); Global Land Evapotranspiration Amsterdam Model (GLEAM); Global PET, Global Aridity, http://www.cgiar-csi.org/data/global-aridity-and-pet-database		
Water location	Change in infiltration	Because of strong modifying impact of management/compaction as well as soil type, as well as influence of root structure, it's not clear there's a good proxy at this point.	None	UN-IGRAC, Global Groundwater Information System (GGIS), https://www.un-igrac.org/global-groundwater-information-system-ggis		
Water timing	Change in physical blockage of water	Change in terrestrial biomass; change in extent of wetlands and inland water bodies	Could get this direct from Nature group?			

6.3.5. Trends in Co-Production

6.3.5.1. General (across all units of analysis)

Assessing trends in water regulation is complicated because changes in water availability are largely a result of changes in climate and in human water extraction and river regulation (Milliman, Farnsworth, Jones, Xu and Smith, 2008). 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 water regulation by ecosystems are therefore generally extrapolated from changes in land use and land management. However, while the mechanisms by which ecosystems regulate water quantity, described above, are reasonably well understood, evaluating the impact of ecosystem change on water regulation remains difficult because the relative dominance of the different processes are not yet well quantified (van Dijk and Keenan 2007). A large and growing body of experimental studies of the water impacts of land use change clearly demonstrate that at small scales ecosystem change affects water distribution (Brown, et al., 2005). Attempts to synthesize data for large watersheds and watersheds with mixed land cover show limited effects, however (Ukkola and Prentice 2013; Peel, McMahon and Finlayson, 2010). This probably reflects the overwhelming influence of precipitation, selection bias in experimental studies, and methodological problems in data analysis (van Dijk, Peña-Arancibia and Bruijnzeel, 2012).

Global trends in deforestation, replacement of perennial vegetation with annual (un-irrigated) cropland, and urbanization have likely increased runoff quantity and also flow speed and size of flood peaks (Jacobson 2011; Ukkola and Prentice 2013). Paired catchment studies have consistently demonstrated that woody vegetation reduces runoff (Bosch and Hewlett 1982; Sahin and Hall 1996; Brown, et al., 2005). Afforestation of grassland, cropland, and shrubland reduces flows by one third to thrTrabuccoee quarters; water quantity reductions from afforestation of grassland are larger than afforestation of shrubland (Farley, Jobbagy and Jackson, 2005; Jackson et al., 2005). The effect of land use change on low flows is about the same in absolute numbers as the effect on annual flows, but the proportionate reduction in low flows is much greater (Farley et al., 2005). Most reviews have found that at least 15-20% of a watershed must undergo a land use change for an impact on water quantity to be measurable downstream (van Dijk and Keenan 2007). Land management that compacts soil, such as grazing or road building, can cause increases in runoff from less than 10% to up to 50% of rainfall (Marshall et al., 2009).

Modeling studies have sought to evaluate trends in runoff at large scales globally. The majority find an increase in runoff, but several contest this; overall, modeling studies have been unable to unambiguously attribute any change in runoff or ET to land use change (Ukkola and Prentice 2013). Of modeling studies that have attributed changes in water fluxes to land use change, they estimate the global net impact to be a decrease of about 5% in ET and an increase in runoff of about 7%, with larger regional impacts (Sterling, Ducharne and Polcher, 2013). Another study suggested that up to 50%, a total of 0.08 mm/year, of changes in global runoff can be attributed to land use change (Piao et al., 2007). Based on changes in ET, models of afforestation in non-forest areas show ~27% of land has a major impact and ~28% has a moderate impact on downstream flows, indicating that more than half of global non-forested land is regulating water quantity (Trabucco et al., 2008). Water regulation was particularly strong in the semi-arid tropics and in conversion to trees from grasslands and subsistence agriculture (Trabucco et al., 2008).

Deforestation and cropland expansion have probably also increased groundwater recharge, while urbanization has decreased recharge. Increased recharge after deforestation has been so large in some places that the water table has risen and salinization is now a problem; in turn, afforestation can lower the water table (Le Maitre et al., 1999).

Changes in groundwater recharge affect dry-season flow. Extensive reviews have found that, across climates, afforestation on a scale large enough to reduce annual flows also reduces low flows by similar absolute amounts, (Farley et al., 2005; Brown, et al., 2005). In humid regions, base flow response to changes in forest cover are varied; increased ET from woody vegetation reduces total water availability, but increased infiltration under forest, especially compared to soil compaction from land management activities like high-density grazing, could increase infiltration and thus base flow (Price 2011). Vegetation has the largest relative impact on recharge in arid climates and over clay soils, though the absolute differences are the smallest under these conditions (Kim and Jackson 2012).

Empirical studies of direct changes in infiltration following land cover change are limited. A 2007 comprehensive review of infiltration following afforestation in agricultural settings found only 4 studies (Ilstedt, Malmer, Verbeeten and Murdiyarso , 2007). Those studies did find increased infiltration under tree cover, but there is no indication that this increased deep drainage to aquifers and thus increased base flow. Where water ponds and there is no partitioning to runoff, any increase in infiltration under woody vegetation is offset by increased ET, so recharge is reduced (Kim and Jackson 2012). Over the last 300 years, one review estimated that the global transition from forest and grassland to rain-fed cropland and pastureland decreased ET enough that groundwater recharge was increased by 2 orders of magnitude (Scanlon, Jolly, Sophocleous and Zhang, 2007).

Water availability changes are largely a result of changes in climate, evapotranspiration, and in human water extraction and river regulation (Milliman et al., 2008). Substantial experimental evidence shows that at small scales increases in woody vegetation reduces runoff and land management that causes soil compaction increases runoff (Bosch and Hewlett 1982; Sahin and Hall 1996; Brown, et al., 2005, Marshall et al., 2009). Woody vegetation also increases evapotranspiration and infiltration, though it is not clear if afforestation-driven increases in infiltration lead to increased base flow (Ilstedt et al., 2007). Trends at larger scales in water regulation by ecosystems are generally extrapolated from changes in land use and land management, though studies are still limited and modeling studies inconclusive (Ukkola and Prentice 2013; Peel et al., 2010). Global trends in deforestation, replacement of perennial vegetation with annual (un-irrigated) cropland, and urbanization have likely increased runoff quantity and also flow speed and size of flood peaks (Jacobson 2011; Ukkola and Prentice 2013). 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 recharge vary significantly by region, increasing in areas of deforestation and cropland expansion, while decreasing in places of urbanization. Groundwater recharge affects temporal flows, particularly during the dry season.

Summary of NCP trends:

- ***Trend*** (& why): Up – “more” regulation, meaning more water quantity available, following global trends in deforestation and conversation from forest and grassland to cropland.
- ***Spatial variance*** (& why): High – Changes in ET have biggest impact in places where ET is water limited
- ***Degree of certainty*** (& why): Moderate. Clear signal of increased water quantity following deforestation, but signal is mixed/muted at large watershed scale

- ***Trend*** (& why): Down – more roads and heavier use of ecosystems
- ***Spatial variance*** (& why): Varied – probably depends a lot on soil type and slope
- ***Degree of certainty*** (& why): Low

6.3.5.2. By Units of Analysis

Unit of Analysis	**Direction of arrow CHANGE IN AVAILABLE WATER**	**Rationale/ justification for why you think this trend is happening**
1. Tropical and subtropical dry and humid forests LUC: Deforestation	UP	Less ET = more water available following deforestation (Bosch and Hewlett 1982, Sahin and Hall 1996, Brown, et al., 2005) For groundwater in flat landscapes, across all climate and soil types in woodlands, on average 6% of water input recharges groundwater (Kim and Jackson 2012)
2. Temperate and boreal forests and woodlands LUC: Deforestation	UP	Less ET = More water available following deforestation (Bosch and Hewlett 1982, Sahin and Hall 1996, Brown, et al., 2005)

		Conifer/hardwood trend? Conifers tend to use more water than hardwoods or eucalypts (Brown, et al., 2005) For groundwater in flat landscapes, across all climate and soil types in woodlands, on average 6% of water input recharges groundwater (Kim and Jackson 2012)
3. Mediterranean forests, woodland, and scrub LUC: Deforestation LUC: Woody encroachment	DOWN	More ET - Changes in ecosystem composition in drylands tend to be shifts to woody, deep rooted species, which reduce water availability downstream (Le Maitre, et al., 2015). Less water available following ecosystem change to more woody vegetation or invasive grasses. Runoff volume strongly controlled by extent of bare soil (Cosandey et al. 2005). In dry savannah, surface runoff is negatively correlated with vegetation cover, so invasive grass encroachment on shrubland or native bunch grasses generally reduces runoff (Wilcox et al., 2012). However, if increased grass cover increases fire frequency, runoff will increase (Wilcox et al., 2012). In water-limited environments, shrub patches generally have higher infiltration and water-holding capacity due to lower raindrop impact, less mechanical crust formation, and less ET plus more surface shading, litter deposition, and mesofaunal activity (Stavi, Lavee, Ungar and Sarah, 2009).
4. Tundra and high mountain habitats	Down	More ET = Less snow shading probably means more ablation and less runoff (Varhola et al., 2010)
5. Tropical and subtropical savannahs and grasslands LUC: Conversion to cropland LUC: Afforestation	UP	More water available following conversion to cropland, less following afforestation. Grasses are annual and shallower rooted than woody vegetation, so grassland have higher relative water yield than forest and less than cropland (Le Maitre, et al., 2015). For tropical grassland and savannah, removal of trees causes less ET, which increases runoff but may also cause less precipitation, (Salazar, Baldi, Hirota, Syktus and McAlpine, 2015) In dry savannah, surface runoff is negatively correlated with vegetation cover, so invasive grass encroachment on native bunch grasses generally reduces runoff (Wilcox et al., 2012). However, if increased grass cover increase fire frequency, runoff will increase (Wilcox et al., 2012).. Conversion of grassland to agriculture is widespread. Grassland to dryland agriculture means less ET, more pronounced for tall grass than short grass conversion (Pielke et al., 2006). In places where grassland or shrubland has been afforested, runoff is decreased on average by 44% (+/- 3%) and 31% (+/- 2%); the total reduction is larger for wet sites and similar for average and low flows, while the relative reduction is larger for low flows (Farley et al., 2005). On average, it is reasonable to expect that afforestation of grasslands will reduce streamflow by one-third to three-quarters (Farley et al., 2005). However, the hydrologic effects of woody encroachment in dry savannah have been mixed (Archer and Predick 2014). In mixed grass-shrub ecosystems, shrubby patches generally have higher infiltration and water-holding capacity (Stavi et al., 2009). Herbivores exert a major control on the hydrologic function of grasslands by compacting soils and thereby increasing runoff and decreasing infiltration (Veldhuis, Howison, Fokkema, Tielens and Olff, 2014; Stavi et al., 2009). Microbiotic crusts in grasslands have conflicting roles, sometimes increasing and sometimes decreasing infiltration, possibly because they absorb water during small rainfall events but fill macropores and so reduce infiltration during large rainfall events (Eldridge and Greene 1994). Both runoff and groundwater recharge are generally increased under cropland compared to grassland (Modernel et al., 2016).

6. Temperate grasslands LUC: Conversion to cropland LUC: Afforestation	Up	More water available following conversion to cropland, less following afforestation. Shift to cultivation from native vegetation in semi-arid regions increases water yield because of reduced interception, reduced ET, shallower rooting depths, and fallow periods (Scanlon et al., 2006). Invasive grass encroachment on native bunch grasses generally reduces runoff, and invasion of annual invasive grasses into semi-arid shrubland and grassland may be as high as 7% (Wilcox et al., 2012) Groundwater recharge in grasslands averages 11% in flat landscapes across all climate and soil types (Kim and Jackson 2012). Temperate grasslands do not necessarily generate much runoff when not grazed (5-7% of rainfall), but soil compaction can dramatically increase runoff (up to 50% of rainfall) (Marshall et al., 2009). Shifting to cultivation generally increases recharge, but it can also reduce recharge by interrupting preferential flow paths, particularly in frozen soil (Scanlon et al., 2006).
7. Drylands and deserts	Flat	Little available water means little change Changes in ecosystem composition in drylands tend to be shifts to woody, deep rooted species, which reduce water availability downstream (Le Maitre, et al., 2015). However, because deserts are water limited, there is generally little to no recharge regardless of vegetation cover (Wilcox et al., 2012). In drylands in general, surface runoff is negatively correlated with vegetation cover (Wilcox et al., 2012). However, if increased grass cover increase fire frequency, runoff will increase (Wilcox et al., 2012). Plants and animals can collect fog and dew for their own needs. In very arid places, it is not clear that this changes the hydrology (i.e. the water is consumed by the organism) (Malik, Clement, Gethin, Krawszik and Parker, 2014, but the ability to capture non-precipitated water and thus exist may influence other NCPs. The one place drylands are not water limited is along rivers, so much attention has been paid to riparian vegetation. Invasive species seem to have about the same ET per area as native species, but if they can colonize a larger area then they will use more water (Hultine and Bush 2011). Because the relative amount of the watershed that riparian vegetation occupies is larger in lower order streams, the impact of riparian vegetation reducing water availability is larger in smaller watersheds (Hultine and Bush 2011). In large watersheds, it appears there would be little impact from removing non-native riparian vegetation (Hultine and Bush 2011) In drylands, infiltration is greater near plants, particularly shrubs, which increase hydrologic conductivity by protecting the surface and creating macropores (Wilcox et al., 2012). Biological soil crusts also play an important role in drylands, affecting infiltration by changing water absorption and forming preferential flow paths. Evidence from field studies suggests that soil crusts have different effects in different climates, reducing infiltration and increasing runoff in hyper-arid regions, mixed effects in arid regions, and increasing infiltration and reducing runoff in semiarid cool and cold drylands (Belnap 2006). In tropical drylands, soil cursts form quickly after first rains and runoff is fast. After herb layer springs up, more infiltration and less runoff (Dubreuil 1985).
8. Wetlands – peatlands, mires, bogs LUC: Draining	Down	Draining wetlands increases peak flows and flood return periods, though impacts vary widely and sometimes include reductions in peak flow (Kadykalo and Findlay 2016; Bullock and Acreman, 2003)
9. Urban/semi-urban LUC: Urban expansion		Because of widespread impervious surfaces in urban areas, surface flow is faster, flood peaks higher, and groundwater recharge reduced (Shuster, Bonta, Thurston, Warnemuende and Smith, 2005). Peak flows can more than double in some urbanized areas (Jacobson 2011). Green

		infrastructure in cities can counterbalance this, but it is not yet widespread.
10. Cultivated areas (including cropping, intensive livestock, farming, etc.) LUC: Conversion from grassland LUC: Conversion from Forest Management: More intensive agriculture	Up	More water available following conversion from some other ecosystem. Change in water quantity depends on what was there before. Because agricultural crops are generally short-season annual and have relatively shallow roots, they usually have less ET than the native vegetation they replace and so will increase water yield in a watershed (Scanlon et al., 2007; Farley et al., 2005; Jackson et al., 2005). Agriculture can include tree crops, which can potentially reduce water yield, but there have been no clear reports of that, perhaps because the tree density isn't high enough (Dimitriou, Busch, Jacobs, Schmidt-Walter and Lamersdorf, 2009). When agriculture is irrigated, the excess water has a major effect on water flows because it is a much larger consumer of water than the ecosystem it replaced, so water yield downstream is reduced (Brauman et al. 2016), though field-scale runoff and infiltration are increased under irrigated agriculture (Kim and Jackson 2012). Generally, abandonment of agricultural lands reduces water quantity because of woody plant encroachment, but the land use history frequently causes soils to be poorer and more bare soil to be exposed; this would reduce ET (Garcia-Ruiz and Lana-Renault 2011). Groundwater recharge is increased over cropland compared to grassland and forest (Kim and Jackson 2012). For groundwater in flat landscapes, across all climate and soil types, on average 11% of water input recharges groundwater in croplands compared to 8% in grasslands and 6% in woodlands (Kim and Jackson 2012). Deforestation for agriculture in Australia increased recharge by up to 2 orders of magnitude (Scanlon et al., 2006), and conversion of savannah to rainfed agriculture in southwest Niger has increased recharge by up to an order of magnitude (Favreau et al., 2009). Agriculture increases recharge because ET under annual crops is low on an annual basis and because high porosity makes the soil surface prone to infiltration - conventional tillage increases infiltration via mechanical soil surface disturbance and conservation tillage through practices such as mulching to increase organic matter in the soil (Armand, Bockstaller, Auzet and Van Dijk, 2009). Crop choice, particularly crops with tap roots, and tillage practices increase biopores and thereby increase infiltration and reduce runoff (Kautz 2015). Physical structures such as contour terraces, cut-off drains, ridging, contour plowing, soil bunds and gabions reduce runoff and increase infiltration (Wakindiki, Mochoge and Ben-Hur, 2007; Biamah, Gichuki and Kaumbutho, 1993). Indigenous conservation practices to reduce runoff include water conservation techniques such as temporary bunds made of crop residue and stone, earth bunds and terraces, and vegetative strips and live fencing, as well as water harvesting practices such as pitting and micro-basins (Wakindiki et al., 2007). These practices are most common on arid and marginal agricultural lands (Wakindiki et al., 2007) Tillage can increase infiltration by breaking soil crusts in arid regions, though it may reduce infiltration in humid regions by removing permanent vegetation and destroying macropores in the soil (Dubreuil 1985). On average, conservation tillage seems to reduce runoff more than conventional practice do, but the impact is small (Armand et al., 2009) One of the most dramatic ways agriculture affects hydrologic flows is via land drainage – when naturally saturated soils are converted to agriculture, ditches or below-ground drains may be installed to reduce waterlogging of crops and thus improve yield. This speeds the movement of water, creating faster and larger flood peaks, increasing baseflow, and moderately increasing overall water yield (Blann, Anderson, Sands and Vondracek, 2009). However, when subsurface drainage is installed, areas with high water-tables, often former wetlands, it can increase soil water storage space and thus reduce flood peaks. Compared to surface drainage, subsurface drainage seems to reduce runoff and peak flow. The effects can be mitigated by the design of the drainage network. The

		impact of both surface and subsurface drainage are strongly affected by soil and climate (Skaggs, Brevé and Gilliam, 1994; Blann et al., 2009) *Trends* Dry season flow and baseflow should increase because of increased infiltration (Kim and Jackson 2012). Abandoning water management structures such as terraces increases mass movement of soil and hydrologic connectivity between the hillslope and channels, creating fast overland flow (Garcia-Ruiz and Lana-Renault 2011)
11. Cryosphere LUC: Melting	Flat?	Warming will have dramatic impacts on hydrology, but it is not clear that biota in this region has a measurable regulating effect (Bring et al., 2016)
12. Aquaculture areas Management: More intensive	NA	No available reviews
13. Inland surface waters and water bodies/ freshwater LUC: Channelization? Management: More pollution		In streams, vegetation directly reduces flow speed (Montakhab et al., 2012). Vegetation also affects the structure of channels, which can in turn affect flow speed (Corenblit et al., 2011)
14. Shelf ecosystems (neritic and intertidal zone, estuaries, mangroves)	NA	Coastal and marine systems are downstream of freshwater bodies. Literature focuses on coastal and marine systems as water sources, not on their role regulating freshwater (Liquete et al., 2013).
15. Open ocean pelagic systems	NA	Coastal and marine systems are downstream of freshwater bodies. Literature focuses on coastal and marine systems as water sources, not on their role regulating freshwater (Liquete et al., 2013).
16. Deep-sea	NA	Coastal and marine systems are downstream of freshwater bodies. Literature focuses on coastal and marine systems as water sources, not on their role regulating freshwater (Liquete et al., 2013).
17. Coastal areas intensively managed and multiply used by people	NA	Coastal and marine systems are downstream of freshwater bodies. Literature focuses on coastal and marine systems as water sources, not on their role regulating freshwater (Liquete et al., 2013).

6.4. Impacts on good quality of life

6.4.1. Different types of value

The value of water is mainly derived from uses including extractive (e.g. agriculture, industry, energy, domestic), in-situ (e.g. transport, hydropower, recreational), and symbolic (e.g. religious).

6.4.1.1. What is the NCP contribution

Sufficient water for is critical for human wellbeing. Water may be removed from surface or groundwater and used for irrigated agriculture, industry, or household use, or water may be used in-situ, including for hydropower production, recreation, fishing, and river transportation. Water may also have symbolic value for cultural and religious reasons. (Brauman et al., 2016; Flörke et al., 2013; Hellegers & Davidson, 2010; Kayser, Moriarty, Fonseca, & Bartram, 2013; Olmstead, 2010; Yokwe, 2009; Molden, 2007; Zwart & Bastiaanssen, 2004; Molden, 2007). Irrigated agriculture is the dominant user of water globally (Brauman et al., 2016; Brauman, Siebert and Foley, 2013; Turral, 2011; Hanjra & Qureshi, 2010; Molden et al., 2007). Changes in nature can change the availability of water for all of these uses. Globally, water stress is increasing, but this is due primarily to changes in demand for water, not to changes in water availability (Brauman et al., 2016; Flörke et al., 2013; Wada, Beek et al. 2011; Turral, 2011; Hanjra & Qureshi, 2010; Liu, Zehnder, & Yang, 2009).

Determining whether a change in water regulation by nature is beneficial depends on the downstream context and is quantifiable only in contrast to the baseline condition against which new regimes of water quantity, location, and timing are compared (Van Dijk and Keenan 2007; Brauman et al., 2016). The impact of changes in water availability on quality of life generally depend on how much water is available in relation to other factors of production.

6.4.1.2. How do we measure the contribution?

Though economic value is just one of the ways that the impact of water on quality of life can be measured, studies of the economic value of water are widespread; economic value varies by use, availability, price, policies, and regulations (Kemper et al, 2017; Hellegers & Davidson 2010; Bozorg-Haddad, Malmier, Mohammad-Azari, & Loáiciga, 2016; Medellín-Azuara, Howitt, & Harou, 2012; Olmstead, 2010; Ferraro, 2009; Arbués, Garcıa-Valiñas, & Martınez-Espiñeira, 2003; Wang & Lall,1999). The value of domestic water, for example, varies by season, weather, and regions, and, at current prices, generally does not change much as price fluctuates (Olmstead, 2014, 2010; Arbués, Garcıa-Valiñas & Martınez-Espiñeira, 2003; Wang and Lall,1999).

6.4.1.3. Substitutability

Because in many cases the value of water lies in its use for irrigation, energy, and transportation, substitutes for those activities that are less water-intensive provide a substitute. For example, transportation via road or rail can substitute for river-based transpiration. Similarly, shifting diets to foods that are less water intensive to produce, switching to varieties of crops that are drought tolerant, cleaning and preparing food with less water, and reducing losses in the post-harvest food value chain by minimizing food waste can functionally substitute for water supply (FAO 2012). When water is scarce, water can be substituted for or quality of life can be improved by increasing agricultural output given the same volume of water consumed (Brauman et al., 2013; Zwart and Bastiaanssen 2004).

Substitutes for regulation of water quantity, location, and timing can be provided by build infrastructure such as dams, river diversion, managed aquifer recharge, inter-basin transfer, and water recycling and reuse (FAO 2012).

6.4.1.4. Status and Trends in impact (value)

Water demand is growing globally (Hanjra & Qureshi, 2010), with water for irrigated agriculture making up most of that demand (FAO, 2018) but demand increasing in the industrial, electric, and domestic water use sectors as well.

6.4.2. Indicators by value

Value type	Indicator/ Proxy	Rationale/ justification for why we this indicator/ proxy was selected	Data set	Scale of Measure – space	Scale of measure - time
Where are people using this and how are they using it. And how scarce is it	e.g. extent of irrigated area. ALSO water shortage, desertification	Irrigated ag: How has the change in water availability led to change in crop production: how has it changed because we have more or less water. Is water the constraining factor. Marginal value			
Market value Irrigated area and population	Energy: how much kw hrs that are dependent on water Ag: irrigated area	Indicators by type of use Extractive In situ Cultural	Need some modifier of scarcity	Population Irrigation over time-seabird/fao Joann Peter: make it fit	

6.5. Summary

Freshwater is critical for human wellbeing, 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 (Haddeland et al. 2014, Brauman et al. 2016). 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 runoff (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 runoff quantity and also flow speed (Sterling et al. 2013, Trabucco et al. 2008). Modeling studies have been unable to unambiguously attribute large-scale measured changes in runoff and evapotranspiration to vegetation change (Ukkola and Prentice 2013, Haddeland et al. 2014).

	Potential Nature's Contributions	**Output of the joint production**	**Impact on good quality of life**
Indicator	Biotic mediation of air-surface-groundwater partitioning (water demand by vegetation, infiltration)	Water availability	Water available for people relative to demand
Trend During the last 50 years: 2 = Major increase (>20%) 1 = Increase (5% to 20%) 0 = No change (-5% to 5%) -1 = Decrease (-20% to -5%) -2 = Major decrease (< -20%)	**-1** Global trends in deforestation, replacement of perennial vegetation with annual (un-irrigated) cropland, and urbanization have likely increased runoff quantity and also flow speed (also flow speed (Sterling, Ducharne and Polcher, 2013, (Trabucco, Zomer, Bossio, van Straaten and Verchot, 2008)	**0** In total, river discharge globally has remained constant over the past 50 years, (Milliman, Farnsworth, Jones, Xu and Smith, 2008).Groundwater has increased in some regions and decreased in others (Rodell et al., 2018).	-2 Human demand for water is increasing worldwide, so water scarcity is increasing (Haddeland et al., 2014; Brauman, Richter, Postel, Malsy and Flörke, 2016)
Spatial variance 3 = opposite trends in different regions 2 = same directional trends in different	**3** Over the past 50 years, rivers discharge has changed in about one-third of major river basins by more than 30% (Milliman et al., 2008). Trends	**3** Surface and groundwater availability has increased in some regions and	2 Impacts vary by region, but all are affected (WWAP 2015)

regions but of contrasting magnitude 1 = similar trends all over the world	in groundwater vary significantly by region, with groundwater increases in areas of deforestation and cropland expansion (Rodell et al., 2018).	decreased in others (Haddeland et al., 2014).	
Variance across social groups 3 = opposite trends for different groups 2 = same directional trends for different groups but contrasting magnitudes 1 = similar trends for all social groups	NA	NA	2 Impacts on people are widely varied depending on adaptation capacity, but all are affected (WWAP 2015)
Degree of certainty 4 = **Well established**: Robust quantity and quality of evidence & High level of agreement 3 = **Established but incomplete**: Low quantity and quality of evidence & High level of agreement 2 = **Unresolved**: Robust quantity and quality of evidence & Low level of agreement 1 = **Inconclusive**: Low quantity and quality of evidence & Low level of agreement	3 The mechanisms by which ecosystems regulate water quantity, described above, are reasonably well understood. However, predicting the impact of ecosystem change on water regulation remains difficult because the relative dominance of the different processes, mediated by climate, geography, and ecosystem management, are not yet well quantified (van Dijk and Keenan 2007)	3 Many studies evaluating trends in water resources, but difficult to attribute changes to particular drivers	3 Many biophysical measures of water scarcity; direct linkages to impacts are less well developed
Two to five most important papers supporting the reported trend	Sterling et al., (2013). "The impact of global land-cover change on the terrestrial water cycle." Nature Climate Change 3(4): 385-390. Trabucco et al., (2008). "Climate change mitigation through afforestation/reforestation: A global analysis of hydrologic impacts with four case studies." Agriculture, Ecosystems & Environment 126(1–2): 81-97.	Haddeland et al., (2014). "Global water resources affected by human interventions and climate change." Proceedings of the National Academy of Sciences 111(9): 3251-3256. Rodell et al., (2018). "Emerging trends in global freshwater availability." Nature 557(7707): 651-659.	WWAP (United National World Water Assessment Programme) (2015). The United Nations world water development report 2015: water for a sustainable world. Paris, UNESCO.

	Milliman et al., (2008). "Climatic and anthropogenic factors affecting river discharge to the global ocean, 1951–2000." Global and Planetary Change 62(3–4): 187-194. van Dijk, and. Keenan (2007). "Planted forests and water in perspective." Forest Ecology and Management 251(1-2): 1-9.		Brauman et al. (2016). "Water depletion: An improved metric for incorporating seasonal and dry-year water scarcity into water risk assessments." Elementa 4. Haddeland et al., (2014). "Global water resources affected by human interventions and climate change." Proceedings of the National Academy of Sciences 111(9): 3251-3256.

6.6. Search methodology

Web of Science search for:
(water OR hydrologic)
AND
("ecosystem service" OR "environmental service" OR "freshwater service" OR "water regulation" OR "freshwater regulation") OR ("water regulation" OR "water quantity" OR "water flow" OR groundwater OR recharge* OR "water partition*" OR infiltrat*) OR ("land use change" OR "land change" OR "land cover change" OR "LULC change")
AND
(vegetation OR ecosystem) OR (forest OR woodland OR scrub) OR (tundra OR mountain) OR (savannah OR grassland OR rangeland) OR (cultivated OR crop OR livestock OR farm) OR (cryosphere OR arctic)
AND
(Review OR “Systematic review” OR Meta-analysis OR Metaanalysis OR “Literature review” OR Synthesis OR Overview OR “Synthesis matrix”)

1718 hits
title screen, left with 258 hits

Followed by: Google Scholar search for variants on “evapotranspiration measurement review”
Followed by: Google Scholar search for variants on “rainfall runoff model review”

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7. NCP 7 - Regulation of freshwater and coastal water quality

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7.1. IPBES Definition:

Regulation – through filtration of particles, pathogens, excess nutrients, and other chemicals – by ecosystems or particular organisms, of the quality of water used directly (e.g. drinking) or indirectly (e.g. aquatic foods, irrigated food and fibre crops, freshwater and coastal habitats of heritage value)

7.2. Why is this NCP important?

7.2.1. What is the big environmental issue this pertains to?

The constituents in water, including minerals, nutrients, other chemicals, and pathogens, influence its suitability for various human uses (Keeler, Polasky et al. 2012). Poor water quality is a critical source of illness in people (Prüss, Kay et al. 2002, Schwarzenbach, Egli et al. 2010), irrigation with saline water is a global threat to agricultural productivity (Pitman and Läuchli 2002), pre-treatment to create ultra-pure water is necessary for many types of manufacturing (Wood, Gifford et al. 2010), and cultural and recreational enjoyment of water bodies is tightly linked to water quality. Globally, water quality is declining, largely driven by human input of waste into water bodies (UNEP 2016). Anthropogenic loading of nitrogen to the environment, for example, has probably doubled ecosystem-available nitrogen (Fowler, Coyle et al. 2013).

7.2.2. How does this NCP play a role?

Nature can both contribute to and remove constituents in water; these changes may be either beneficial or harmful depending on the desired use of 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. Whether a change in water quality is considered beneficial depends on the suite of desired uses of water (Keeler, Polasky 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).

7.3. (Co-) production

7.3.1. How is it produced?

<u>Contribution of constituents to water</u>

Vegetation contributes leaf litter and bulk debris to streams (Helmers, Eisenhauer et al. 2005) as well as providing dissolved organic matter through soil water (Leenheer and Croué 2003). Ecosystems fix nitrogen naturally, and this can move to water bodies (Fowler, Coyle et al. 2013). Sediment in water bodies comes from both the terrestrial landscape and from the re-suspension of sediments that are already in lakes and streams (Walling and Fang 2003). Some ecosystems, particularly heavily managed ones such as urban areas, agriculture, and timber plantations, receive substantial inputs of nutrients and other potential pollutants and therefore contribute many of these constituents to surface and groundwater bodies. Waste from human settlements and agricultural runoff are considered to be the largest contributors to poor water quality (UNEP 2016).

Additions to water bodies, through processes of vegetation senescence (Dosskey, Vidon et al. 2010), by intercepting and then depositing airborne pollutants (Weathers and Ponette-González 2011), or because of direct heavy loading, may be positive or negative.

Removal of constituents from water - mechanisms

Ecosystems remove pollutants dissolved or entrained in water through physical (deposition, infiltration), geochemical (sorption, precipitation, occlusion), and biological (plant or microbial uptake) retention (Roberts, Stutter et al. 2012). These processes work in tandem; above-ground vegetation physically reduces surface flow speed, enabling sediment deposition, sorption, and infiltration (Arora, Mickelson et al. 2010, Sweeney and Newbold 2014). Dense root systems increase permeability and porosity of soil and thereby increase infiltration (Roberts, Stutter et al. 2012). Groundwater entering an ecosystem laterally or via infiltration interacts with soils and the rhizosphere, where it can be taken up by plants or denitrified by microbes (Roberts, Stutter et al. 2012, Sweeney and Newbold 2014).

Ecosystems can take up nutrients, including nitrogen and phosphorus, as well as pesticides, herbicides, petroleum, and metals (Williams 2002, Krutz, Senseman et al. 2005, Arora, Mickelson et al. 2010). Plants may be selected and selectively planted to uptake certain chemicals from soil and soil-water, a process called phytoremediation (Mirza, Mahmood et al. 2014) (Salt, Smith et al. 1998). Ecosystems that sequester but do not break down toxic materials may need to be harvested; sequestered compounds can then be recycled or waste more easily disposed of (Mirza, Mahmood et al. 2014). Ecosystems that are taking up pollutants may saturate, losing their effectiveness, and sometimes remobilizing once-sequestered pollutants (Hoffmann, Kjaergaard et al. 2009, Roberts, Stutter et al. 2012). For ecosystems to regulate water quality, placement is critical, as potential ecosystem pollutant sinks must be in a flow path of contaminated water (Rittenburg, Squires et al. 2015).

Aquatic processing of nutrients and other contaminants is also important (Rabalais 2002). Though these processes can be critical for removing contaminants from water, the processes themselves may be detrimental because they occur in the form of algal blooms (Rabalais 2002). In-stream processes are moderated by riparian buffers, which may provide inputs to the system as well as temperature control via shading, which can then affect in-stream processes and growth of in-stream vegetation (Helmers, Eisenhauer et al. 2005). Animals, particularly aquatic animals, regulate nutrients, pollutants, and particles through ingestion and excretion and also by physically perturbing soils and vegetation (Withers and Jarvie 2008).

Sediment is another important constituent of water quality. Nature's role in regulating sediment production via erosion processes is largely addressed in NCP 8. Here, we note only briefly that sediment export from the land surface to aquatic environments has increased steadily over time, though in the past 50 years the amount of sediment in rivers and exported to the ocean has declined in many places because sediment has been retained behind large dams (Syvitski and Kettner 2011). Sediment moves off the land surface both through sheet erosion and mass wasting, including gullies and bank collapse (Fox and Wilson 2010). Continuous vegetative cover improves both hillslope (Zuazo and Pleguezuelo 2009) and bank stability (Fox and Wilson 2010), and root mass is also critical for soil stability and thus reduced erosion (Gyssels, Poesen et al. 2005). Soil crusts are also important in places where vegetation is sparse (Eldridge and Greene 1994). As with nutrients and chemicals, the effectiveness of buffers in retaining sediment that has already been mobilized varies considerably (Gumiere, Le Bissonnais et al. 2011). In aquatic environments, both vegetation (Wang, Zheng et al. 2015) and fauna (Macisaac 1996)are important for removing sediments from the water column, although bioturbation can also re-suspend sediments (Krantzberg 1985). Over time, the vegetative control over sediment moving into and within rivers actually shapes the form of rivers

(Statzner 2012).

Removal of constituents from water - effectiveness
Waste from human development and runoff from agricultural fields are the primary causes of poor water quality, so controlling these inputs directly is critical to improving water quality (UNEP 2016). Once unwanted constituents have gotten into water, nature's ability to remove them is mixed. Many types of pollutant-removal by ecosystems are a function of loading, so more removal occurs when more pollutants are present (Smith, Swaney et al. 2003, Bouwman, Van Drecht et al. 2005).

Grass, trees, or shrubs at the edge of an agricultural field, frequently referred to as a buffer, is the setting for which ecosystem regulation of water quality is most commonly quantified, though the mechanisms and presumably the effectiveness are similar for all types of water quality regulation. Buffers demonstrate mixed efficiency at pollution removal and reflect a large number of factors, including soils, slope, precipitation patterns, and size of buffer area (Polyakov, Fares et al. 2005). Buffer-strip effectiveness is lower in cold climates, where a large fraction of nutrient export occurs before vegetation has begun to grow (Han, Xu et al. 2010), suggesting the importance of nutrient processing by vegetation.

Removal of dissolved pollutants in surface flow by buffers is moderate, with about 40% removal effectiveness (Mayer, Reynolds et al. 2007). Removal efficiency for pesticides in solution is similar, averaging of 45% with a range from 0 to 100% retention (Arora, Mickelson et al. 2010). High water flows are probably the most important factor in reducing buffer strip effectiveness (Sweeney and Newbold 2014).

Buffers also remove pollutants from surface flow by trapping sediments and the pollutants that are sorbed to them. On average, buffers 10 m wide trap about 65% of sediments delivered by overland flow, while 30-m buffers trap about 85% of sediments (Sweeney and Newbold 2014). Again, variation is high, with efficiency ranging from 54 to 100% (Liu, Zhang et al. 2008). Phosphorus is frequently sorbed to sediment, and 41-95% of sorbed P is, on average, removed by buffers (Roberts, Stutter et al. 2012) (Hoffmann, Kjaergaard et al. 2009). An average of 76% of pesticides sorbed to sediments are removed by buffers, with a range of 2-100% (Arora, Mickelson et al. 2010). Buffers at the edge of forestry operations are also very effective at reducing sediment delivery to water bodies (Norris 1993).

Experiments done in controlled conditions with very low flows have frequently shown little additional water quality benefit from buffers exceeding 10 m wide, but experiments focused on more realistic situations, including heterogeneous flows and high flows, found that removal efficiency increases with width, which can help make up for selective flow paths through buffers (Sweeney and Newbold 2014).

Buffers also remove pollutants from water below ground. Removal of dissolved pollutants such as nitrogen in subsurface flow through a buffer is quite effective (Mayer, Reynolds et al. 2007). Nitrate removal efficiency averages 55% (range: 26-64%) for buffer widths <40 m and 89% (range: 27-99%) for buffer widths >40 m (Sweeney and Newbold 2014). N removal can occur below the rooting zone, and these soil processes do not seem to be altered by above-ground disturbance (Sudduth, Perakis et al. 2013)

Because geographic conditions play such a large role in buffer effectiveness, there is no clear consensus on the magnitude of effects at watershed scale (Sweeney and Newbold 2014).

Water quality is regulated by a variety of wet and aquatic ecosystems as well. Wetlands and floodplains are effective at removing pollutants (Hoffmann, Kjaergaard et al. 2009), and the interface between water and soil at a streambank is critical for processing nutrients (Lawrence, Skold et al. 2013). Within streams, vegetation improve water quality by stabilizing the channel as well as entraining and sequestering pollutants (Montakhab, Yusuf et al. 2012). In stream processing of pollutants is varied and a function of loading, but between 0 and 50% of N can be processed in stream (Sudduth, Perakis et al. 2013). In coastal environments, seagrass entrains suspended sediments, removing it from the water column (Adams, Hovey et al. 2016). Throughout the marine environment, marine denitrification constitutes a substantial part of the nitrogen cycle (Fowler, Coyle et al. 2013).

Summary of how this NCP is produced:
- ***Direct***: Deposition of organic matter into water by ecosystems
- ***Direct***: Uptake of nutrients and other pollutants into ecosystems
- ***Indirect***: Some types of ecosystems are more likely to entrain pollutants, and their location relative to sources of pollutants indicates whether they are providing a regulating service.

7.3.2. How is it measured?

Though measuring water quality is reasonably straightforward, measuring ecosystem regulation of water quality much more complex. Though the mechanisms by which ecosystems regulate water quality are well understood, the aggregate impact of those processes is not. Water quality regulation is therefore generally measured as either 1) a mass balance, in which changes in water quality up and down stream of an ecosystems are quantified; 2) using models which aim to account for processes of pollutant uptake; and 3) by using land use as a direct proxy for either pollutant addition or removal.

Filtration efficiency can be measured as the difference in concentration of the pollutant of interest before and after it passes through a buffer, the mass of pollutant held in the buffer, or changes in pollutant concentration at an outflow point before and after buffer installation (Norris 1993, Arora, Mickelson et al. 2010, Sudduth, Perakis et al. 2013). These measurements require intensive and ongoing efforts, however, and depending on how they are designed may not replicate field-scale flows; as a result, pollutant removal in practice has general been found to be lower than under experimental conditions (Helmers, Eisenhauer et al. 2005, Liu, Zhang et al. 2008).

A variety of models, ranging from simple mass-balance to spatially distributed process models have been developed to track and predict changes in water quality due to land use (Donigian and Huber 1991, Borah and Bera 2003). These models help translate plot-scale studies to watershed scales (Dosskey 2001). However, they still require substantial data for parameterization and calibration.

In practice, water quality is frequently assumed to be related to various land cover types (Ponette-González, Brauman et al. 2015). Buffers are generally considered to have capacity to absorb those pollutants and thus provide a filtration service. In addition, unmanaged ecosystems without added nutrients or pollutants that might be replaced by managed ecosystems where pollutants area added (agriculture or urban areas) are sometimes considered to provide filtration.

7.3.3. Links to other NCPs (if applicable)

NCP 3 – regulation of air quality – Pollutants in the air can be deposited in water

NCP 4 – regulation of climate – Changes in water input (precipitation) lead to more or less water for dilution
NCP 6 – **water flow regulation** – more water means more dilution
NCP 8 – Soils – soil quality is critical to infiltration and reduced erosion
NCP 9 - Natural Hazard impact reduction – floods – high water flows during flooding often entrain substantial land-based material into water, reducing water quality

Water quality affects the production of:
NCP 11 - Energy
NCP 12 - food and feed
NCP 13- materials
NCP 14 – medicines

Cultural context is critical in the quality of water demanded for various activities, so its value is a function of
NCP 15 – learning
NCP 16 – Physical and psychological experiences
NCP 17 - Identity

7.3.4. Indicators of NCP (co-) production

NCP	**Production Function**	**Indicator/ Proxy**	**Rationale/ justification for why this indicator/ proxy was selected**	**Data set**	**Scale of Measure – space**	**Scale of measure - time**
Filtration	Absorbent (unmanaged) ecosystem between pollution source and waterway	In cropland, area that's not cultivated or prevalence of buffer strips. In urban, green cover. Overall, existence of non-crop or urban in a place dominated by either		*Some kind of detailed land cover map? Sub-national stats on adoption of buffer strips or green infrastructure*		

7.3.5. Trends in Co-Production

7.3.5.1. General (across all units of analysis)

Though the status and trends in water quality are beginning to be quantified globally (UNEP 2016), extensive and robust measures or models of ecosystem regulation of water quality are very limited.

Nutrient loading from anthropogenic sources, particularly agriculture and wastewater, has increased dramatically over the past 50 years (Smith, Swaney et al. 2003). This reflects both expansion of agricultural land and increased nutrient inputs on new and existing agricultural land (FAOSTAT). Expansion of agricultural land leaves less ecosystem area available for nutrient removal, so less natural regulation of water quality is probably occurring. However, because nutrient processing tends to be a function of loading, nutrient processing in still-existing ecosystems has likely increased (Bouwman, Van Drecht et al. 2005)

A little over half of global reactive nitrogen is processed on land; the rest is processed in marine systems (Fowler, Coyle et al. 2013). Between 50 and 70 Tg of nitrogen is leached from land to the ocean in fresh waters every year (Fowler, Coyle et al. 2013), perhaps double what it would be without anthropogenic inputs of nitrogen (Schlesinger 2009). The amount of phosphorus in rivers has probably also doubled (Filippelli 2008).

Thought overall land use change has created more sources than sinks of contaminants to water, in some cases the recognition of the effectiveness of nature-based water treatment has led to increased adoption. The effectiveness of wetland for treating wastewater has been recognized for at least a century; this has been measured and codified to the point that constructed wetlands are now a widely recognized and certified water treatment solution (Vymazal 2011). Similarly, the benefits of agricultural buffers is now well-recognized enough that the use of buffer strips has been mandated in some places (Lee, Smyth et al. 2004), though this is a small fraction of global farmland.

Summary bullet list of NCP trends (your assessment and rationale, briefly):

- ***Trend*** (& why): Down – expansion of landscapes that are net polluters (primarily agricultural and urban areas where), means there is less land is available to provide filtration. However, filtration seems to be largely a function of loading, so as pollutant inputs increase, so does filtration.
- ***Spatial variance*** (& why): Spatial variance is large. Pollutant loading varies enormously and pollutant filtration varies in turn. Adoption of buffer strips and green infrastructure increases filtration in regions with heavy loading.
- ***Degree of certainty*** (& why): Medium. Increase in pollutant loading from various landscapes is well documents. Vegetative filtration does work, but its efficacy varies substantially.

7.3.5.2. By Units of Analysis

Unit of Analysis	Direction of arrow	Rationale/ justification for why you think this trend is happening
1. Tropical and subtropical dry and humid forests LUC: Deforestation	Down	Nutrient pulse following conversion, subsequent impacts depend on new land cover. Inputs from agriculture are higher than from forest. Less N cycling in pasture soils could mean less N export, and grass cover reduces N flow paths (Tomasella, Neill et al. 2009). In plantations, intercropping with an herbaceous cover crop reduces erosion substantially (Sidle, Ziegler et al. 2006)
2. Temperate and boreal forests and woodlands LUC: Deforestation	Down	Nutrient and sediment pulse follows deforestation, but regrowth quickly moderates impact. (Tomasella, Neill et al. 2009). Timber harvesting increases sedimentation (Croke and Hairsine 2006). Fire increases export of sediment, nutrient, and other pollutants, suggesting these are being sequestered naturally {Smith, 2011 #4083}
3. Mediterranean forests, woodland, and scrub LUC: Deforestation LUC: Woody encroachment	Down	De-vegetation decreases filtration, but abandonment of agricultural lands may increase filtration (Garcia-Ruiz and Lana-Renault 2011)
4. Tundra and high mountain habitats LUC?	Up	More sediment export from shrubland than grassland, even when grasses are invasive {Wilcox, 2012 #387}
5. Tropical and subtropical savannahs and grasslands	Down.	Especially semi-arid savannahs are very sensitive to disturbance {Jacobs, 2007 #4084}. Conversion to agriculture means less area to filter

LUC: Conversion to cropland LUC: Afforestation		
6. Temperate grasslands LUC: Conversion to cropland LUC: Afforestation	Down	Conversion to agriculture means more input of pollutants and less filtration
7. Drylands and deserts LUC: Overgrazing and vegetation removal (?)	Flat	N input is limited, so little filtration activity (Seitzinger, Harrison et al. 2006)
8. Wetlands – peatlands, mires, bogs LUC: Draining	Down	Worldwide, wetlands remove about 17% of anthropogenic reactive nitrate inputs. (Jordan, Stoffer et al. 2011). Reduction in wetland area by drainage and channelization has reduced overall wetland filtration ability, but individual wetlands are very effective and are often protected or constructed specifically for filtration purposes (Williams 2002)
9. Urban/semi-urban LUC: Urban expansion	Down	In urban areas, pollutant loading is high and large areas of impermeable surface moves water quickly and reduces possibilities for filtration (TSIHRINTZIS and HAMID 1997). However, planned expansion of green areas within the urban matrix provide substantial filtration, though they can also be a pollutant source in the form of leaf litter
10. Cultivated areas (including cropping, intensive livestock, farming, etc.) LUC: Conversion from grassland LUC: Conversion from Forest Management: More intensive agriculture	Down	Cropland is major source of nutrient pollution, stemming from addition of nutrients on farm, quick movement of nutrients to waterways via drainage, and drainage of wetlands that would historically have processed some of the nutrients in water (Blann, Anderson et al. 2009). In general, less sediment in rivers after farmland abandonment (Garcia-Ruiz and Lana-Renault 2011)
11. Cryosphere LUC: Melting	?	Nutrient and carbon export from artic in rivers is strongly controlled by ecosystem processes and will change with climate change, but not clear how (Bring, Fedorova et al. 2016)
12. Aquaculture areas LUC? Management: More intensive	Down	Food sources to fish aquaculture increase water pollution. However, Shellfish aquaculture removes nutrients. net removal of 0.28 g N year^{-1} per animal (Ferreira and Bricker 2016)
13. Inland surface waters and water bodies/ freshwater LUC: Channelization? Management: More pollution	Up	Freshwater systems (groundwater, lakes, rivers) account for about 20% of total global denitrification.,(Seitzinger, Harrison et al. 2006). Rivers have a median denitrification rate of 16% but denitrification can be as large as 60% (Mulholland, Helton et al. 2008). N removal by large streams gets higher over a small range of inputs, but both large and small streams saturate (Mulholland, Helton et al. 2008). The reported range of P cycling efficiencies is large but can be up to 60% at low flow, though P is in general turned over and so eventually becomes available in some form downstream (Withers and Jarvie 2008) Lakes can hold 10-50% of P input (Withers and Jarvie 2008) . Overall, in-stream processing has probably increased because loading has increased.
14. Shelf ecosystems (neritic and intertidal zone, estuaries, mangroves)	Up	Spatially distributed global models of denitrification suggest that continental shelf sediments account for 44% of total global denitrification (Seitzinger, Harrison et al. 2006). Increased

LUC ?		processing with increased loading. Seagrass reduces sediment in water (Adams, Hovey et al. 2016)
16. Deep-sea LUC ?		Spatially distributed global models of denitrification suggest that oceanic oxygen minimum zones (OMZs) are responsible for 14% of total global denitrification (Seitzinger, Harrison et al. 2006)
17. Coastal areas intensively managed and multiply used by people LUC ?		Estuaries are responsible for ~1% of total global denitrification (Seitzinger, Harrison et al. 2006).

7.4. Impacts on good quality of life

7.4.1. Different types of value

7.4.1.1. What is the NCP contribution

People value water filtration for a variety of reasons. When water is directly consumed, environmental regulation of water quality can improve health outcomes by reading nutrients, pathogens, and other pollutants in water (Townsend and Howarth 2010; (Jordan, Stoffer et al. 2011). In setting with waterworks, including for domestic and industrial supply, the cost of water treatment can be reduced if pollutants are removed from water before treatment, in some cases because pollutants must be removed to meet health standards and in other cases because sediments or other constituents in water hinders operations.

For those reliant on fisheries and for recreational water users, excess nutrients in water can cause algal blooms that make recreation in or on the water unpleasant, and in extreme cases can cause hypoxic zones that kill fish and other aquatic life (Dodds and others 2009; Howarth and Marino 2006; Pinckney and others 2006)e. There are also substantial non-material benefits to people knowing that the water is clean.

7.4.1.2. How do we measure that value/contribution?

The value of regulation of water quality is measured in a variety of ways (Keeler et al, 2012), including by the avoided cost of water treatment, economic methods such as additional travel to cleaner lakes and increased value of homes near clear water bodies, heath measures, and through religious and origin narratives about clean water.

7.4.1.3. Substitutability

Substitutes for output of high water quality include changes in the final handling or use of water, such as moving the intake of a water system to a location with cleaner water. The natural regulation of water quality can be substituted for by removing unwanted constituents in water in other ways, such as by building water treatment plants, and by avoiding putting unwanted contaminants in water in the first place.

7.5. Summary

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 (Pruss et al. 2002). Though access to clean water is increasing and water-borne disease is decreasing, these trends are uneven across user groups (WHO and UNICEF 2017, Ezzati et al. 2002). 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 (UNEP 2016, Smith et al. 2003). 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 (Keeler, et al. 2012; Bernhardt 2013). 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 and Newbold 2014).

	Potential Nature's Contributions	**Output of the joint production**	**Impact on good quality of life**
Indicator	Capacity of ecosystem to filter (or add) constituent components (extent of vegetation)	Concentration of constituents (pollutants) in the water	a) Reduced incidence of water borne disease b) Avoided water treatment costs
Trend During the last 50 years: 2 = Major increase (>20%) 1 = Increase (5% to 20%) 0 = No change (-5% to 5%) -1 = Decrease (-20% to -5%) -2 = Major decrease (< -20%)	**-1** Natural systems have the capacity to remove pollutants dissolved or entrained in water through physical, geochemical, and biological retention, but the effectiveness of pollutant removal varies tremendously (Mayer, Reynolds, McCutchen and Canfield, 2007) (Sweeney and Newbold 2014). Impervious surfaces and removal of vegetation have reduced potential filtration.	**-1** Water quality has decreased globally, with nutrient pollution and pathogens increasing and industrial waste having mixed trends (UNEP 2016).	a) 1 Water-related disease accounts for approximately 4% of the global burden of disease and has been decreasing (Pruss, Kay et al. 2002) (Ezzati, Lopez, Rodgers, Vander Hoorn and Murray, 2002). b) -1 Increases in extent and quality of water treatment and sanitation have increased global spending on water infrastructure (WHO and UNICEF 2017)
Spatial variance 3 = opposite trends in different regions 2 = same directional trends in different regions but of contrasting magnitude	**2** The extent and pace of vegetation removal varies globally but overall urbanization and	**3** Regions where industrial pollution are well controlled show improved water quality, but	a) 2 Water-borne disease prevalence differs substantially worldwide and has been decreasing

1 = similar trends all over the world	impervious surfaces have increased (Seto, Güneralp, and Hutyra, 2012)	nutrient pollution has increased everywhere and organic pollution has increased in places with growing urban populations and insufficient sewage treatment (UNEP 2016).	everywhere, though at different rates (Pruss, Kay, Fewtrell and Bartram, 2002) b) 2 Spending on water infrastructure has increased globally, but at different rates (WHO and UNICEF 2017)
Variance across social groups 3 = opposite trends for different groups 2 = same directional trends for different groups but contrasting magnitudes 1 = similar trends for all social groups	NA	NA	a) 2 Water-borne disease prevalence differs substantially among social groups; it has been decreasing everywhere, though at different rates. Different diseases are becoming prevalent. (UNEP 2016) b) 2 All groups are increasing spending on water infrastructure, but by differeing amounts. (WHO and UNICEF 2017)
Degree of certainty 4 = **Well established**: Robust quantity and quality of evidence & High level of agreement 3 = **Established but incomplete**: Low quantity and quality of evidence & High level of agreement 2 = **Unresolved**: Robust quantity and quality of evidence & Low level of agreement	2 The mechanisms by which ecosystems filter water are well-understood, but the effectiveness of filtration varies widely among studies (Mayer, Reynolds, McCutchen and Canfield, 2007)	3 Many small studies and some government reporting, but globally consistent water quality indicators and measurement are still lacking. (GEMS/Water 2018)	a) 4 Water-borne disease is well studied (WHO and UNICEF, 2017). b) 4 Expenditures on infrastructure are not necessarily well-tracked, but exent and expansion of infrastructure is

1 = **Inconclusive**: Low quantity and quality of evidence & Low level of agreement	(Sweeney and Newbold 2014).		monitored (WHO and UNICEF 2017)
Two to five most important papers supporting the reported trend	Mayer, Reynolds, McCutchen and Canfield, 2007). "Meta-Analysis of Nitrogen Removal in Riparian Buffers." Journal of Environmental Quality **36**(4): 1172-1180. Sweeney and Newbold, 2014). "Streamside Forest Buffer Width Needed to Protect Stream Water Quality, Habitat, and Organisms: A Literature Review." JAWRA Journal of the American Water Resources Association **50**(3): 560-584. Seto, Güneralp, and Hutyra, 2012). "Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools." Proceedings of the National Academy of Sciences **109**(40): 16083.	UNEP (2016). A Snapshot of the World's Water Quality: Towards a global assessment. Nairobi, Kenya, United Nations Environment Programme: 162. Smith et al., (2003). "Humans, Hydrology, and the Distribution of Inorganic Nutrient Loading to the Ocean." BioScience 53(3): 235-245. GEMS/Water (2018). Progress on Ambient Water Quality – Piloting the monitoring methodology and initial findings for SDG indicator 6.3.2, UN Environment on behalf of UN-Water.	Ezzati, Lopez, Rodgers, Vander Hoorn and Murray, 2002). "Selected major risk factors and global and regional burden of disease." The Lancet 360(9343): 1347-1360. (Pruss, Kay, Fewtrell and Bartram, 2002). "Estimating the Burden of Disease from Water, Sanitation, and Hygiene at a Global Level." Environmental Health Perspectives 110(5): 537-542. UNEP (2016). A Snapshot of the World's Water Quality: Towards a global assessment. Nairobi, Kenya, United Nations Environment Programme: 162. WHO and UNICEF (2017). Progress on drinking water, sanitation and hygiene: 2017 update and SDG baselines. Geneva, World Health Organization (WHO) and the United Nations Children's Fund (UNICEF).

7.6. Search methodology

Web of Science search for:
(water OR hydrologic)
AND
(("ecosystem service" OR "environmental service" OR "freshwater service" OR "water regulation" OR "freshwater regulation") OR ("water regulation" OR "water quantity" OR "water flow" OR groundwater OR recharg* OR "water partition*" OR infiltrat*) OR ("land use change" OR "land change" OR "land cover change" OR "LULC change"))
AND
(vegetation OR ecosystem) OR (forest OR woodland OR scrub) OR (tundra OR mountain) OR (savannah OR grassland OR rangeland) OR (cultivated OR crop OR livestock OR farm) OR (cryosphere OR artic)
AND
(Review OR “Systematic review” OR Meta-analysis OR Metaanalysis OR “Literature review” OR Synthesis OR Overview OR “Synthesis matrix”)

1718 hits
title screen, left with 258 hits

Followed by: Specific additions from bibliographies of included papers, including other papers by same authors

Followed by: Google Scholar search for variants on “buffer function review”
Followed by: Google Scholar search for variants on “global nitrogen export review”

Total included in review: 58 papers

7.7. References

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8. NCP 8 - Formation, protection and decontamination of soils and sediments

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8.1. IPBES Definition:

Sediment retention and erosion control, soil formation and maintenance of soil structure and processes (e.g. such as decomposition and nutrient cycling) that underlie the continued fertility of soils important to humans. Filtration, fixation, degradation or storage of chemical and biological pollutants (pathogens, toxics, excess nutrients) in soils and sediments that are important to humans.

8.2. Why is this NCP important?

8.2.1. What is the big environmental issue this pertains to?

Soil is the solid material on the Earth's surface resulting from interactions of the hydrosphere, biosphere, lithosphere and atmosphere with the underlying hard rock (Jenny, 1941and1980). Soil is a fundamental natural resource providing food, fibre, and energy. It plays a central role in a wide range of human activities and supports many NCP (Blum, 2005; Frossard et al., 2006). However, is well established in many parts of the world that soil loss rates are one to two orders of magnitude greater than average soil formation rates (FAO and ITPS, 2015).

Soil contamination (pollution) is one of the ten major soil threats identified in the 2015 Status of the World's Soil Resources report (FAO and ITPS, 2015), and soil contamination because of anthropogenic activities is a widespread problem globally (Bundschuh et al., 2012; DEA, 2001; EEA, 2014; Luo et al., 2009; SSR, 2010). Concern over soil contamination stems primarily from health risks. Soil pollution has a direct impact on food security (FAO, 2006) and there is a direct link between the quality and safety of the food we eat and the level of soil pollutants (Tóth et al., 2016). Additionally, soil pollution affects food availability by reducing crop yields due to toxic levels of pollutants that hamper crop growth and reduce soil biodiversity (Vargas et al., 2016).

8.2.2. How does this NCP play a role?

Soil is a basic resource and the foundation of all civilizations (Hillel 1992; Young and Crawford 2004) as well as serving as a major link between climate and biogeochemical systems (Yaalon, 2000). Soils are also a key reservoir of global biodiversity, ranging from micro-organisms to flora and fauna. This biodiversity plays a fundamental role in supporting soil functions and therefore NCP associated with soils. Soil provide NCP by performing six essential functions (USDA 2014; Clothier et al. 2009; Doran 2002; Robinson et al. 2013):

1. Serving as a media for growth for plants and providing habitat for animals that live in the soil.
2. Regulating water by absorbing, holding, releasing, and altering most of the water in terrestrial systems. Soil thereby helps control where rain, snowmelt, and irrigation water goes. As water and dissolved solutes flow over the land or into and through the soil, soils filter that water.
3. Transforming wastes and nutrients by storing, transforming, and cycling carbon, nitrogen, phosphorus, and other nutrients.
4. Filtering and buffering potential pollutants as minerals and microbes in soil degrade, immobilize, and detoxify organic and inorganic materials, including industrial and municipal by-products and atmospheric deposits. Direct effects of pollutants in soil may not be immediately revealed because soils to store and immobilize them (FAO and ITPS, 2015).

5. Modifying the atmosphere by emitting, absorbing, and storing gases (carbon dioxide, methane, water vapour, and the like) and dust.
6. Providing engineering media for construction of foundations, roadbeds, dams and buildings, and protecting archaeological artefacts.

8.3. (Co-) production

8.3.1. How is this NCP produced?

Healthy soils are living systems; they boast a huge diversity of micro-organisms. These microbes maintain soil structure, regulate nutrient and water cycles within the soil and the atmosphere (including soil detoxification and decomposition of organic matter), sequester carbon, and are involved in symbiotic relationships with plants (some bacteria and fungi capture atmospheric nitrogen and convert it into a usable form for plants). The ability of a soil to support any of these functions depends on its structure; composition; and chemical, biological, and physical properties, all of which are both spatially and temporally variable (Blum, 1993; Harris et al., 1996; Jenny, 1980; Karlen et al., 1997).

Living organisms are one of the environmental factors are responsible for the soils we have today (Jenny 1941), though soil formation is a complicated natural process influenced by climate, relief, mountain rocks, organisms, and time (FAO, 2015a). In general, all soil formation begins with the accumulation of parent material. Next is the build-up of organic materials. Pioneer species (most often grasses and alga) live and die and organic matter builds up on the surface of the parent material and also beneath the surface in the rooting zone. Accumulation of organic material is often the first visible soil forming process and is initiated by burrowing soil fauna such as earthworms. By digestion of organic and mineral material, soil fauna promote the formation of the clay mineral complex and homogenise the top soil by the transport of fine textured material. The burrowing activity of earthworms creates stable and continuous macro pores (Lal, 1988).

Soils develop over time and are therefore part of a dynamic system. Many soils are formed within time spans of 100 to 10,000 years because it takes about 100 to 200 years to form each inch of soil, on average, and most soils are 5 to 6.5 feet deep. Quantifying the rate of soil formation has become important in response to the consideration of soil as a renewable resource.

Soil microflora is a key component of soils that not only plays a significant role in the basic soil processes but is also actively involved in enhancing soil fertility and thus crop productivity. Microbial activity in soil has a strong impact on its physical properties and bioremediation and biocontrol of phytopathogens in agricultural soils. Soils become nutrient-rich from the growth and decay of deep, many-branched grass roots. Roots, both living and dead, hold the soil together and provide a food source for living plants. Living organisms affect the structure of soils. Conversion of tree species and liming can decrease soil compaction (Muys 1989). Vegetation affects soil biological activity and humus quality while liming increases earthworm activity.

When soil moisture is high, as in wet or humid climates, there is a net downward movement of water in the soil for most of the year, which usually results in greater leaching of soluble materials, sometimes out of the soil entirely, and the translocation of clay particles from upper to lower horizons. In arid climates there is net upward movement of water in the soil, due to high evapotranspiration rates by vegetation growing on the soil surface, which results in upward movement of soluble materials such as salts. These accumulated materials can become cemented, making them impenetrable to roots and lowering infiltration tremendously.

Soils can store and immobilize pollutants. The degree of retention of pollutants is influenced by the presence of other pollutants and their concentration, quantity of oxygen, humidity, temperature, pH, nutrients, bio- augmentation, products of co-metabolism, and so on. Soil pollution destroys the physical, chemical, and biological balance, which ensures soil fertility. Soil pollution can inhibit enzyme activity, reducing the diversity of fauna and flora.

Summary bullet list of how this NCP is produced:

- ***Direct***: Soils are formed by the interactions of lithosphere, biosphere, hydrosphere and atmosphere.
- ***Direct***: Soils are formed through the transformation of unconsolidated geological materials by pedogenic processes through the effects of natural soil formation factors.

8.3.2. How is (co)production of this NCP measured?

Soil formation can be measured through the thickness, types, and arrangement of soil horizons. Soils can be classified as either renewable or non-renewable based on soil formation to loss ratio (Grierson, 1992). This assessment must be made over time spans that can yield statistically reliable data to verify whether soil is forming faster or slower after changes to management or treatments have been incurred (Friend,1992). Monitoring soil depth within cropping systems or forests will help scientists gauge a soil's base ground renewal rate. A preliminary analysis of available world data on rates of soil formation indicates that a likely, satisfactory time period to monitor gross changes in soil or land is from 11 to 15 years. How developed a soil is can be determined from looking at the profile?
Soil Electrical Conductivity (EC) has a strong relationship with other soil characteristics and is easier, less expensive, and faster than other soil property measurements (Seifi et al., 2010).

There are a variety of approaches to monitoring and remediating contaminants in soils (Pascucci 2011). The toxicity of metal contaminated soils has been assessed with various bioassays (Hirano and Tamae 2011). Visible and near-infrared reflectance spectroscopy has potential for the estimation of various heavy metal concentrations in soil (Shi et al., 2014).
Soil microorganisms are bioindicators of soil health and activity. The earthworm could be a useful living organism for bio-monitoring of soil pollution because of their bio-accumulative ability (Hirano and Tamae 2011).

8.3.3. Links to other NCPS

NCP2 – pollination –

NCP3 – air quality – Soil play very important roles to improve air quality though out the remulation of CO_2, N_2O and CH_4 emissions, carbon sequestration(FAO and ITPS,2017), and reducing the negative environmental effects of pesticides, heavy metals and other pollutants

NCP4 – climate – Soil regulates CO_2, N_2O and CH_4 emissions and is important for carbon sequestration (FAO and ITPS,2017). In turn climate has an important role in soil formation. Soils in warmer or wetter climates are more developed than soils in cooler or drier climates. Warm conditions promote the chemical and biological reactions that develop parent material into soil. Climate may have strong or weak, permanent or periodical, and primary or secondary impact on soil processes as shown in the following table (Szabolcs,1990; Varallyay,1990 and 1994, 2002).

Soil Degradation Processes	Climatic Sceneries				Causative Factors	
	Cold and Dry	Cold and Wet	Hot and Wet	Hot and Wet	Natural	Anthropic

Soil Erosion by Wind	4	1	4	1	1,2,3	9,10,11,12
Soil erosion by Water	3	4	2	4	3	9,10,11,12
Acidification	3	1	4	1	2,4	13,15
Salinization/Alkalization	2	4	1	4	5,6,8	14
Physical Degradation	3	2	2	1	-	10,12
Water Logging	4	1	4	2	5,6,7	11,12,14
Biological Degradation	3	2	2	1	-	11,16
Soil pollution	2	3	3	4	-	16

1 = strong , 2 = Medium , 3 = Slight , 4 = Negligible

Causative Factors:

1-Undelating
2 – Parent Rock
3- Lack of Permanente and dense vegetation
4- Litter Decomposition
5- Low laying land
6- Improper drainage
7- High water table(non saline)
8- High water table(saline)
9- Deforestation
10- Overgrazing
11- Improper tillage practices
12- Irrational land use
13- Irrational fertilizer application
14- Improper irrigation
15- Acid deposition
16- Chemical soil pollution

NCP6 – water quantity – Water is important for the transformation and translocation of soil components through soil profile and leading to soil formation. In general, the rate of soil formation of humid regions is greater than those of arid regions due to more available water.

NCP7 – water quality – Soil filters and buffers substances in soil water and transforms contaminants . Erosion control affects the amount of sediment in water; too much or too is a water quality issue

NCP9 – hazards – sediment is disproportionately produced during heavy rain events often related to flooding

NCP10 – pests – Soils are a basic prerequisite to producing biomass (energy), food, fodder, fiber, and other products, (FAO,2015). Soils also have a direct influence on the ability to distribute food, the nutritional value of some foods and, in some societies, access to certain foods through local processes of location and preferences (Gregory, 2012).

NCP11 – energy - The medians of the net of energy values vary from one location to other depending on soil types and increase in the direction from the heavy to light soils and from dry to wet year(Woli, et al.2012).

NCP12 – food – Soils most obviously contribute to food security in their essential role in crop and folder production , so affecting the local availability of particular foods. They also have a direct influence on the ability to distribute food, the nutritional value of some foods and ,in some socrties, the access to certain foods through local processes of location and preferences (Gregory, 2012).

NCP13 – materials –

NCP14 – medicine – Soil contains a wide array of tiny microhabitats that create enormous variation in soil microbes. This diverse group of microbes, of which there are billions in an average teaspoon of soil, compete with one another; the methods microbes use to subdue other microbes in the soil can be adapted to fight infections in the human body (Brady and Weil ,1999). It has been estimated that nearly 80 percent of antibacterial agents approved between 1983 and 1994 have their origin in the soil (FAO and ITPS, 2015). More recently, an antibiotic from an uncultured soil bacterium that can kill the causal agent of tuberculosis (*Mycobacterium tuberculosis*) has been identified (Wall et al. 2015).

NCP15 – learning –
NCP16 – experiences -
NCP17 - identities -

8.3.4. Indicators of NCP (co-) production

NCP	Production Function	Indicator/ Proxy	Rationale/ justification for why this indicator/ proxy was selected	Data set	Scale of Measure – space	Scale of measure - time
soil	soil degradation	Rain-use efficiency adjusted NDVI.	Gibbs, H. K. and J. M. Salmon (2015). "Mapping the world's degraded lands." Applied Geography 57: 12-21. AND Bai, Z. G., et al. (2008). "Proxy global assessment of land degradation." Soil Use and Management 24(3): 223-234.	http://www.fao.org/geonetwork/srv/en/metadata.show?id=37061&currTab=simple	0.07 degree	1981–2003

8.3.5. Trends in Co-Production

8.3.5.1. General (across all units of analysis)

Deeper soils on flatter country and in well protected positions due to natural forest cover may well be forming faster than their loss rate, but because real soil formation rates are rarely measured, no one really knows which soils are "renewable," depth-stable, or forming at a rate equivalent to the measured soil loss rate (Hall,et al.1982). At the very least, a basic background figure of 150 years per inch worldwide (with a range of 100 to 200 years per inch) can be assumed. On that basis alone, any land or development that will result in the loss of more than 0.06 inch of soil per year could be considered non sustainable.

Erosion hazard, defined as very steep slopes (>30%) or moderately high slope (8–30%) accompanied by a sharp textural contrast within the soil profile, varies from 10% for soils of North Africa and Near East to 20% for soils of Europe.

<u>Summary bullet list of NCP trends</u> (your assessment and rationale, briefly):

- ***Trend*** (& why): The rate of soil formation as reflected by type, number, arrangement and thickness of horizons are highly affected by climatic conditions. In general, the rate indicator of soil formation increases from the soils of arid regions to more humid regions due to the effect of more available water for pedogenic processes to be more active, as well as, more dense forest vegetation.
- ***Spatial variance*** (& why): Type and amounts for the dominant soil components (mineral and organic fractions) vary from one ecological region to other due to the variation with one or more of soil formation factors and the activity of the pedogenic processes which related to climatic conditions.

- ***Degree of certainty*** (& why): Remarks of soil formation can be recognized clearly with high certainly in the soil of humid regions rather than arid regions due to the availability of soil moisture..

Soil contamination is mostly assoaciated with heavy agricultural and industrial activities in developed countries. In developing countries, it is mostly concentrated in oil producing countries and those with high population densities. While efforts are underway to manage soil pollution in developed countries, there still a long way to go for developing countries

8.3.5.2. By Units of Analysis

Unit of Analysis	Direction of arrow	Rationale/ justification for why you think this trend is happening
1. Tropical and subtropical dry and humid forests	Up	Increasing soil moisture will increase the net downward movement of water in the soil, which usually results in deeper soil profile (White,1987).
LUC: Deforestation	Down	Deforestation will Increasing soil loss by erosion processes
2. Temperate and boreal forests and woodlands	Down	soil formation has been influenced by forest vegetation, are generally characterized by 'litter layers', recycling of organic matter and nutrients, including wood, and wide varieties of soil-dwelling organisms(Boyle,2005). Boreal forest soils are typically low in fertility and acidic, with a thin A horizon (Turkington,2001)
LUC: Deforestation		
3. Mediterranean forests, woodland, and scrub	Up	Soil formation in a Mediterranean climate show a moderately deep soil profile with a more or less well-defined clay illuviation in the subsoil and the development of a characteristic red matrix colour(Verheye and Rose,2005)
LUC: Deforestation LUC: Woody encroachment		
4. Tundra and high mountain habitats	Down	The tundra region derives its name from the Finnish word "tunturia," which means treeless plain. The tundra is characterized by a harsh, frost-laden landscape, minus-zero temperatures, lack of precipitation, nutrients, and extremely short seasons. Divided into two major categories, the artic tundra and alpine tundra, the tundra environment is characterized by a distinct climate, flora and fauna(Barretto ,.2017).
LUC		
6. Temperate grasslands		The soil of the temperate grasslands is deep and dark, with fertile upper **layers**. It is nutrient-rich from the growth and decay of deep, many-branched **grass** roots. The rotted roots hold the soil together and provide a food source for living plants.
LUC: Conversion to cropland LUC: Afforestation		
7. Drylands and deserts		Soils in dry areas do not have a lot of plants, and therefore, they do not have a lot of organic matter. Also, there are very little soil microbes to convert plant matter into organic matter. The dry soils are vary ,they can be deep or shallow.
LUC: Overgrazing and vegetation removal (?)		
8. Wetlands – peatlands, mires, bogs		Bog soils dominated by slow growing mosses occur in very wet, cool climates in sites where ground water is minimal, so that growth depends on nutrients brought in with rainwater. The plant communities of peat-forming mires have simple floristics and share many species in a total flora of about 250 species (Helman et al. 1988, McDougall and Walsh 2007).
LUC: Draining		

8.4. Impacts on good quality of life

8.4.1. Different types of value

8.4.1.1. What is the NCP contribution

Soils are a basic prerequisite to producing biomass (energy), food, fodder, fiber, and other products, (FAO,2015). Soils also provide habitat, modify the atmosphere, regulate water quantity and quality, and provide engineering media.

8.4.1.2. How do we measure that value/contribution?

Health impacts of soil contamination are a primary way that direct impacts of soil NCP are measured (Tóth et al., 2016).

The impact of soil NCP is often measured by its absence and its effect on the production of other NCP. For example, soil degradation and pollution reduces crop yields (NCP 12) (Vargas et al., 2016).

Changes in soil protection affect water quality (NCP 7) and water-related hazards such as flooding (NCP 9). Soil loss and sediment in rivers, lakes, and reservoirs is often a problem, reducing, for example, reservoir capacity to store water and produce hydroelectricity. However, reducing erosion and therefore the input of sediment to streams and floodplains can be equally detrimental, causing, for example, the sinking of New Orleans and Venice.

8.4.1.3. Substitutability

The NCP of soil fertility can be substituted for by the addition of either mineral fertilizer or nutrient management techniques such as conservation tillage, crop rotation, and organic fertilization. It is also possible to grow crops without soils through the process of hydroponics.

Erosion control can be substituted for with built infrastructure such as berms and dams. Once erosion has occurred, soils can be moved from other locations.

Contaminant regulation by soils would be unnecessary if soils were not polluted.

8.4.1.4. Status and Trends in impact (value)

Erosion negatively affects crop yields by reducing 'the plant population and by depleting fertility factors(Baboule et al.,1994).
Soil pollution has a direct impact on food security (FAO, 2006.Contaminants can be taken up by plants and accumulate in the food chain, compromising the safety of the food consumed by both humans and animals (Tóth et al., 2016).

8.4.2. Indicators of NCP impact

8.4.2.1. Indicators by value

Value type	Indicator/ Proxy	Rationale/ justification for why we this indicator/ proxy was selected	Data set	Scale of Measure – space	Scale of measure - time
Soil fertility	Crop yield	It appears that the relationship between yield ratio, land degradation and soil fertility is not very strong(Keyzer and Sonneveld,2001).		national	1994

Erosion control	Soil depth	The risks of global annual loss of food production due to accelerated erosion may be as high as 190×10^{6} Mg of cereals, 6×10^{6} Mg of soybeans, 3×10^{6} Mg of pulses, and 73×10^{6} Mg of roots and tubers(lal,2010)	Global	2010
Contaminant regulation	Food security	Soil pollution has a direct impact on food security (FAO, 2006.Contaminants can be taken up by plants and accumulate in the food chain, compromising the safety of the food consumed by both humans and animals (Tóth et al., 2016).	Global	

8.5. Summary

Soil is a fundamental natural resource which people rely on for the production of food, fibre, and energy. The properties of different soils affect fertility and thus crop production (Foster,1981;and Lathum,1994). Soils also filter and buffer pollutants, cycle nutrients, and hold and store water (USDA 2014, Clothier et al. 2009, Doran 2002; Robinson et al. 2013). Soil is considered a non-renewable resource as it takes thousands of years to form from eroding rocks and sediments and requires very specific topographical, meteorological, and biological conditions (FAO,2015b).

	Potential Nature's Contributions	**Output of the Joint Production**	**Impact on good quality of life**
Indicator	**Soil biodiversity**	**Soil Quality**	**Soil degradation impact on crop productivity**
Trend During the last 50 years: 2 = Major increase (>20%) 1 = Increase (5% to 20%) 0 = No change (-5% to 5%) -1 = Decrease (-20% to -5%) -2 = Major decrease (< -20%)	- 1 Poor land-management practices and environmental change are affecting belowground communities globally which cause a decline in soil biodiversity	- 1 Decline in soil carbon, biodiversity, nutrients and increase in soil erosion, compaction, contamination, sealing, crusting and desertification due to poor soil management practices	-1 Crop yield reduction is associated with soil degradation, irrespective of whether improved agricultural practices are being applied or not (Sonneveld et al., 2016).
Spatial variance 3 = oposite trends in different regions 2 = same directional trends in different regions but of contrasting magnitude 1 = similar trends all over the world	3 The variations between regions, soil types and soil management practices lead to opposite in different regions	3 The variations between regions, soil types and soil management practices lead to opposite in different regions	3There are examples of where soil degradation(erosion) has had no effect or has had a positive effect on crop production (Lal and Moldenhauer, 1987). Crop productivity in northern Europe is not likely to be significantly reduced by soil erosion (Bakker et al., 2007)

Variance across user groups 3 = opposite trends for different groups 2 = same directional trends for different groups but contrasting magnitudes 1 = similar trends for all social groups			**3** User groups vary greatly in their capacity to compensate the reduction in crop production due to soil degradation. Higher income crop producers can use fertilizers
Degree of certainty 4 = **Well established**: Robust quantity and quality of evidence & High level of agreement 3 = **Established but incomplete**: Low quantity and quality of evidence & High level of agreement 2 = **Unresolved**: Robust quantity and quality of evidence & Low level of agreement 1 = **Inconclusive**: Low quantity and quality of evidence & Low level of agreement	4	4 Decline soil quality and well known problem	3 Decline in crop yield as the results of soil degradation is established, but more work in is needed to better understand the contrasting trends among regions and social groups
The two most important papers supporting the reported trend	FAO and ITPS (2015). Status of the World's Soil Resources (SWSR) – Main Report. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy Hunt, H.W. and D.H. Wall. 2002. Modeling the effects of loss of soil biodiversity on ecosystem function. Global Change Biology, 8:33-50	FAO and ITPS (2015). Status of the World's Soil Resources (SWSR) – Main Report. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy Guo , L. B., & Gifford, R. M. (2002). Soil Carbon Stocks and Land use change: a met analysis. Global Change Biology, 8(4), 345-360	Sonneveld, B. G. J. S. , M. A. Keyzer and D. Ndiaye (2016). Quantifying the impact of land degradation on crop production: the case of Senegal. Solid Earth, (7): 93–103 Rattan Lal & William C. Moldenhauer (1987) Effects of soil erosion on crop productivity, Critical Reviews in Plant Sciences, 5:4, 303-367, DOI: 10.1080/07352688709382244 Bakker M. M., Govers G., Jones R. A. and Rounsevell M. D. A. (2007) "The Effect of Soil Erosion on Europe's Crop Yields", Ecosystems 10:1209–1219

Nature contributes to better soil quality through improvement in soil biodiversity, but mainly in enhancing soil organic carbon (SOC) which is a strong determinant of soil quality, soil health and crop productivity. SOC is also agreed to play a crucial role in soil formation, soil protection as well other functions and ecosystem services (FAO and ITPS, 2015; FAO, 2017a; Gaiser et al., 2013). Globally, poor soil management practices have led to a decline 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 and ITPS, 2015; Lal, 2015a). These trends are not uniform globally, however, improving in North America for example where the majority of cropland has shown improvements in SOC stores due to the widespread adoption of conservation agriculture (e.g. reduced tillage and improved residue management) (Pierzynski and Brajendra, 2017; FAO and ITPS, 2015; Lal, 2015b). Despite discrepancies in country and regional estimates of SOC stocks (Köchy et al., 2014; Hengl et al., 2017; Hartemink et al., 2010 and Sanchez et al., 2010), FAO (2017) suggests that more than 60% of the 680 billion tonnes of carbon is found in ten countries: Russia, Canada, USA, China, Brazil, Indonesia, Australia, Argentine, Kazakhstan and Democratic Republic of Congo.

Soil degradation is the physical, chemical and biological decline in soil quality. It is caused by erosion (wind and water), salinity, loss of organic matter, decline in fertility, increase in soil acidity and alkalinity, decline in soil structure (increase in soil compaction and surface sealing and soil contamination which all affect crop productivity. Among these factors, soil erosion is the biggest threat to crop productivity as it removes organic matter, nutrients and prevents vegetation growth, which negatively affects overall biodiversity (Panagos et al., 2018; Scherr, 2000). However, the consequences of land degradation are severe especially for poorer societies that do not have the available means to compensate loss of land productivity (Blanco-Canqui and Lal, 2010). For example, crop productivity in northern Europe is not likely to be significantly reduced by soil erosion, however, for the southern Europe the threat of erosion-induced productivity declines is stronger (Bakker et al., 2007)

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9. NCP: 9 - Regulation of hazards and extreme events

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9.1. IPBES Definition:

Amelioration, by ecosystems, of the impacts on humans or their infrastructure caused by e.g. floods, wind, storms, hurricanes, seawater intrusion, tidal waves, heat waves, tsunamis, high noise levels, fires

Reduction, by ecosystems of hazards like landslides, avalanches

Increase, by organism, of probability of hazards (e.g. beaver dams affecting floods)

9.2. Why is this NCP important?

9.2.1. What is the big environmental issue this pertains to?

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, Hoyois et al. 2016). Less-developed countries and those with less robust institutions tend to be more affected by disasters (Kahn 2005). Changing drivers, including the risks of climate change and increased vulnerability of populations, are increasing both the incidence and impacts of disasters (Van Aalst 2006).

9.2.2. How does this NCP play a role?

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, Sudmeier-Rieux et al. 2013). Nature-based approaches to disaster risk reduction are becoming increasingly appealing because they are frequently lower-cost than built infrastructure and related approaches to disaster risk reduction and because they frequently provide a suite of co-benefits that built infrastructure cannot.

9.3. (Co-) production

9.3.1. How is this NCP produced?

Nature helps regulate hazards and their impacts through a variety of mechanisms. 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, keeping the abiotic elements of an ecosystem in place, 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. The role of nature in coastal protection, landslide reduction, floods and flood impact, and fires are discussed below.

<u>Coastal Protection:</u>

A growing body of research indicates that ecosystems have the potential to ameliorate the impacts of coastal hazards on humans and infrastructure by attenuating waves, securing sediments, and reducing storm surge (Spalding et al. 2014, Bridges et al. 2015, Sutton-Grier et al. 2015, Beck and Lange 2016, Gedan et al. 2011, Shepard et al. 2011, Pinsky et al. 2013, Barbier et al. 2013, Narayan et al. 2016, Gittman et al. 2014). For example, coastal forests, such as mangroves, and intertidal vegetation, such seagrass and saltmarsh, can attenuate waves, reduce storm surge, inhibit re-suspension of sediments, and stabilize soils (Koch et al. 2009, Wamsley et al. 2010, Gedan et al.

2011, Shepard et al. 2011, Pinsky et al. 2013, Barbier et al. 2013, Moller et al. 2014, Moller et al. 1999, Zhang et al. 2012, Mazda et al. 1997). Coral and oyster reefs also attenuate waves and trap sediments (Beck and Lange 2016, Monismith 2007, Ferrario et al. 2014, Scyphers et al. 2011, Gourlay 1994, Meyer et al. 1997, Piazza et al. 2005, Borsje et al. 2011). While reefs may have less influence on surge or large storm waves, they filter out the high energy waves over the long-term, creating a nearshore wave climate that is conducive to the growth of coastal vegetation which in turn have their own ameliorating effects (Meyer et al. 1997, Piazza et al. 2005, Guannel et al. 2016). Seagrass beds reduce water flow and waves, as well as retaining sediments through soil stabilization and turbulence reduction near the bed (Bradley and Houser 2009, Koch et al. 2009, Nepf 2012, Chen et al. 2007). Through their higher elevation, dunes can protect coastal communities from flooding; they also supply sediment to beaches following storm events (Silva et al. 2016, Duran and Moore 2013).

In general, protective services provided by coastal ecosystems can be classified as hydrodynamic or sedimentary processes (Koch et al. 2009, Nepf 2012, Moller et al. 1999, Gourlay 1994, Maza et al. 2013, Luhar and Nepf 2016, van Rooijen et al. 2016). At the most fundamental scale, a plant stem immersed in moving fluid experiences viscous and drag forces. These forces in turn cause plants to move, further perturbing the surrounding fluid and promoting turbulence, which dissipates energy. Similarly intricate local flow patterns also emerge around the irregular geometry of rigid organisms like coral reefs and mangroves (Monismith 2007). These complex interactions between submerged habitats and nearshore waters ultimately translate into energy extracted from the mean flow, which underlies the commonly observed and reported wave attenuation (or “hydrodynamic dampening”) by coastal ecosystems.

Hydrodynamic conditions are interlinked with shoreline geomorphology through erosion of the bed and sediment transport processes. Marsh and mangrove shoots and roots trap sediments (Gedan et al. 2011, Boorman and Ashton 1997, Wolanski et al. 1998), thus enhancing coastal protection by raising the local topography over the course of years. Dense, deeply submerged seagrass canopies may have relatively little dampening effect on the propagating waves, but their inhibition of near-bed turbulence may play an important role in trapping and avoiding resuspension of fine sediments (Nepf 2012, van Rooijen et al. 2016, Yang et al. 2013) that would otherwise be carried further away by the flow. This sediment retention could in turn protect a sandy beach from erosion in a single event or in the long-term. Soil stabilization provided by vegetation (Michelli et al. 2002, Gedan et al. 2011, Nepf 2012) makes it more difficult for waves and currents to erode the bed, potentially influencing bathymetry (Chatenoux and Peduzzi 2006).

Although the effect of vegetation on soil may seem inherently protective, accurate quantification of this process is needed to avoid undesired trade-offs. For example, a densely vegetated sand dune may resist erosion and protect inland areas from flooding. However, too little erosion can starve adjacent beaches under extreme events (Silva et al. 2016), indirectly promoting coastline retreat. Moreover, like built approaches to shoreline protection (e.g., seawalls) ecosystems have a threshold beyond which they fail and can no longer protect people and property. Energetic waves can tear up plants (Mork 1996, Mendez and Losada 2004), expose sediments, and increase erosion as seen both in the laboratory (Coops et al. 1996) and in the field (Knutson et al. 1981, Cahoon 1996). Plants also bend or break in rapid unidirectional flows (Nepf 2012, Maza et al. 2013), offering less resistance to the flow (Gedan et al. 2011, Moller et al. 2014), thus losing much of their dampening effect. Unlike dense aquatic meadows, sparse submerged canopies can enhance local turbulence, causing increased bed shear stress and thus potential scour near the base of the plants (Nepf 1999, Tinoco and Coco 2016).

In sum, the production of coastal protection services varies dramatically according to several abiotic and biotic variables. These include the type of hazard (e.g. storm waves vs. tsunami) and its magnitude (e.g., flow speed, wave height etc.), as well as spatial variation in shoreline elevation and type (e.g., muddy or sandy versus rocky). Various attributes of species morphology are particularly important, such as the density and geometry of blades, shoots, and trunks for mangroves, saltmarsh and seagrass (Koch et al. 2009, Gedan et al. 2011, Beck and Lang 2016) and the distance between reef crest and water level, the width of the reef shelf, the distance offshore (i.e., fringing versus barrier reef) and roughness for coral reefs (Monismith et al. 2007, Ferrario et al. 2014, Narayan et al. 2016, Scyphers et al. 2011). The width of the natural buffer can have large influences on the degree to which habitats ameliorate coastal hazards and importantly, different species of coral, kelp, mangroves and other systems, may have very different morphologies (e.g., *Porites divaricata* vs. *Acropora palmate* coral and *Macrosystis pyrifera* vs. *Laminaria hyperborea*) and thus different magnitudes and mechanisms of influence on coastal protection services (Elwany et al. 1995, Mork 1996).

<u>*Summary of how this NCP is produced*</u>:
Direct: Coastal ecosystems dissipate energy
Indirect: Configuration of multiple habitat types (e.g., coral reef, mangrove forests, saltmarshes) that provide coastal protection through different mechanisms and may interact with each other over the short and long-term to ameliorate the effects of coastal hazards through wave attenuation, surge attenuation, and avoided sedimentation or soil erosion.
Indirect: Marginal effects of ecosystems relative to other abiotic factors such as shoreline type, orientation and elevation, forcing conditions (waves, wind, surge), sea-level rise which all influence the extent to which the distribution and extent of coastal habitats matter for reducing erosion and flooding impacts for people and property.

<u>Landslides</u>
A landslide is a specific sub-type of natural hazards involving the downslope movement of rock, soil, and organic materials due to the effects of gravity (Highland and Bobrowsky, 2008). The term landslide refers both to this slope movement as well as to the resulting landform. Landslides occur when the forces resisting movement (e.g., cohesion and friction) are exceeded by the forces driving instability (e.g., gravity), which involves some mechanism that triggers the instability (Lu and Godt, 2013). Triggers include other hazards such as earthquakes (e.g. Collins and Jibson, 2015) or volcanic eruptions (e.g., Glicken, 1996), as well as triggers related to climatic factors such as hillslope hydrological processes (Iverson, 2000; Lu and Godt, 2013; Bogaard and Greco, 2016) and erosional processes (e.g., Collins and Sitar, 2008).

Although biota could have the potential to marginally influence the distribution of landslides triggered by earthquakes or volcanic eruptions, the primary seismic or volcanic hazard dominates the resulting impact to humans. Thus, the possible impact of biota on co-seismic and volcanic landslides is likely negligible and has not been studied in detail. In contrast, hydrologically triggered landslides involve some combination of increased subsurface pore-water pressure and decreased shear strength of the mobile earth materials (Iverson, 2000; Lu and Godt, 2013; Bogaard and Greco, 2016), both of which can be influenced by vegetation and potentially also by some animals.

Vegetation is known to influence slope stability in two primary ways: by influencing hydrological processes and through the apparent strength properties of soils (Glade et al., 2005). Through the process of transpiration, vegetation removes water from the subsurface, which decreases antecedent soil moisture and pore-water pressures, generally reducing the susceptibility of a slope to failure during a subsequent rainfall event. In some circumstances forest clearing can therefore lead to enhanced landslide susceptibility (Eigenbrod and Kaluza, 1999). During storms, vegetation canopy can intercept precipitation, some portion of which evaporates and never reaches the subsurface, which further decreases soil moisture and thereby enhances the stability of vegetated slopes (Dhakal and Sidle, 2004). Vegetation also influences the strength of hillslope materials by introducing root strength, which can reinforce the slope and reduce the probability of landsliding (e.g., Schmidt et al., 2001). Although not widely studied, burrowing and grazing animals can change subsurface hydraulic and strength properties of soils, which, depending on the type of change, can either increase or decrease a slopes susceptibility to landsliding. However, limited research has focused specifically on the topic and is typically considered in the broader context of land-use change (e.g. Glade, 2003).

Erosion-triggered landslides involves a change in topography that undermines some portion of the slope leading to an instability and failure. Through the same processes of canopy interception and root strength, vegetation can reduce erosion, therefore in some cases reducing the probability of landslides. Burrowing and grazing animals generally contribute to natural erosional processes, and while the direct link to landslide susceptibility remains poorly characterized it could lead to some increase.

Overall the locations of interest related to NCP and landslide occurrence are steep terrain where vegetation change (e.g. change in forest structure, or deforestation) is likely to take place.

<u>*Summary of how this NCP is produced*</u>:
Direct: Root strength enhances slope stability
Indirect**:** Transpiration reduces slope wetness
Indirect: Canopy interception and evaporation reduce slope wetness
Indirect: Grazing and burrowing can alter subsurface properties and erosion

<u>Flood control</u>
Nature regulates the generation of flood waters, the conveyance of flood waters, and the impact of floods.

The mechanisms by which nature affects flood generation are the same as those described in detail in NCP6 Regulation of water quantity and flow. Briefly, ecosystems can reduce the size of flood peaks by creating storage space in the soil to retain water because vegetation transfers water to the atmosphere and through physical blockage of water flow (Brauman, Daily et al. 2007). Flood regulation affects primarily small to mid-size floods and floods at small spatial scales (Van Dijk, Van Noordwijk et al. 2009) (Fletcher, Andrieu et al. 2013); ecosystem flood regulation has been found to be negligible for events higher than 20% mean annual flood (Dadson, Hall et al. 2017) and is most effective during storms with lower rainfall intensities (Depietri, Renaud et al. 2012). In some cases, particularly with headwater wetlands, ecosystems can exacerbate flooding (Kadykalo and Findlay 2016). Ecosystem management, particularly the placement of roads, substantially affects flooding (Eisenbies, Aust et al. 2007).

Ecosystems also regulate the speed at which water moves across the landscape and through channels, which affects the timing and size of flood peaks. (Brauman, Daily et al. 2007). Vegetation with high contours or relief is most likely to slow floodwaters (Lyytimäki and Sipilä 2009). Within streams, vegetation stabilizes riverbanks and reduces river energy and flow speed (Palmer, Filoso et al. 2014) (Bechtol and Laurian 2005) (Elosegi and Sabater 2013).

Nature can also reduce the impact of flooding; floodplains and wetlands provide space for floodwaters to expand, reducing the height and energy of downstream flood peaks (Kadykalo and

Findlay 2016). Ecosystems may also help combat land subsidence by promoting groundwater recharge, helping protect low-lying areas. (Bechtol and Laurian 2005)

Summary of how this NCP is produced:
Direct: Evapotranspiration by vegetation creates storage space for flood waters in the subsurface
***Direct*:** Rough vegetation slows water movement
***Direct*:** Natural channels slow flow speeds and floodplains and wetlands provide room for floodwaters to expand

Fire control
Ecosystems have a profound effect on fire due to the patterns of fuel amount, spatial distribution and availability to burn (periodic dryness)(Archibald, Lehmann et al. 2013). People can and do manipulate fire to increase the benefit and reduce the impact, though accidental fire can also increase the impact (Bowman, Balch et al. 2011). In fire prone ecosystems, the great majority of species are adapted to fire, but the nature of that adaptation varies, so that for each species there is a minimum time to reach reproductive maturity after a fire within which time a second fire will cause possible loss of that species. Likewise there is also a maximum period after fire when the species will be lost due to natural death in the absence of a second fire. This defines the tolerable fire interval required to maintain a species in an area.

Two types of landscape fire are recognized: wildfire and prescribed burning. The main objective of prescribed burning is to reduce the area burnt by wildfire, and the associated risk. In practice the effectiveness of these programs is hard to measure, but research suggests that between 1 and 10 ha of prescribed burning is required to reduce wildfire area in the long term (Price and Bradstock 2010, Price, Russell-Smith et al. 2012, Price, Pausas et al. 2015). Prescribed burning is more effective in ecosystems with higher natural fire frequencies and slower fuel recovery rates (Price, Pausas et al. 2015). Prescribed burning, or the deliberate burning of landscapes has a history extending thousands of years in all continents (Bowman, Balch et al. 2011, Jones 2012, Abrams and Nowacki 2015). Prescribed burning usually occurs in smaller patches, in milder weather, in cooler seasons, and with less intensity or severity that wildfire (Russell-Smith, Yates et al. 2007), though there is considerable overlap between the two.

Summary of how this NCP is produced:
Direct: Vegetation growth controls fuel amount and ability to burn

9.3.2. How is (co)production of this NCP measured?

Nature's contribution to disaster risk reduction is measured in a variety of ways. The direct physical processes by which nature interacts with hazard-drivers can be measured in laboratory settings, such as with sea grasses in flumes. Measurements in-situ more accurately represent real-works conditions but frequently occur in complex settings that make it difficult to disentangle the role of nature. In-situ, measurements are frequently made of hazard elements like wave high before and after the wave comes in contact with an ecosystem such as a seagrass bed. Indirect measures of the role of nature are often made by statistically comparing the impact of disasters in places with and without natural hazard reduction and through modeling studies. Vulnerability indices, which account for the presence of certain natural characteristics along with characteristics of vulnerable human populations, are also used to measure the impact of nature in hazard reduction.

Coastal Protection
At local scales coastal protection is generally measured by placing wave sensors in and around coastal habitats such as seagrass (Bradley and Houser 2009), saltmarsh (Moller et al. 1999, Shephard et al. 2011), kelp forests (Elwany et al. 1995), and coral reefs (Ferrario et al. 2014). The overarching

goal of such studies is often to quantify wave attenuation through vegetation and across reefs (Koch et al. 2009, Pinsky et al. 2013) or to assess local scale shoreline accretion or retreat (Feagin et al. 2009, Scyphers et al. 2011, Shephard et al. 2011). Another goal of wave attenuation studies in the laboratory and field is to estimate the drag coefficient (Pinsky et al. 2013). The drag coefficient is an important part of extrapolating the influence of vegetation at the local or patch scale to a larger seascape scale using quantitative models. Accurate parameterization of the drag force or energy dissipation caused by vegetation (Kobayashi et al. 1993, Mendez and Losado 2004, Bradley and Houser 2009, Maza et al. 2009, Luhar and Nepf 2006, van Rooijen et al. 2016) is difficult because of the complexity of the physical phenomena involved and wide variety and variability of attributes (geometry, stiffness, density, buoyancy, etc.) of nearshore vegetation (Nepf 2012). Similarly, coral reefs are characterized by a complex geometry and spatially variable roughness, which are difficult to parameterize in numerical models (Monismith 2007).

Ideally, quantifying production of coastal protection services at larger scales involves isolating the contribution of one or more coastal or marine ecosystems relative to the bathymetry, distance from shore, wave height, and other abiotic variables (Koch et al. 2009, Pinsky et al. 2013, Guannel et al. 2015, NRC 2014). This is because amelioration of coastal hazards by habitats varies tremendously based on forcing conditions and shoreline morphology (see production section above). However, modeling coastal processes and nearshore hydrodynamic conditions is difficult and time intensive. Much of the work related to coastal hazard modeling involves highly complex surge and wave models that forecast impacts of storms of varying sizes on coastal regions and communities. Recent advancements in these models include incorporating parameters that reflect the role of coastal habitats in reducing flooding and erosion and the ability to assess trends in coastal protection as a result of habitat change through time. However, many of these models require several months, extensive data, and highly trained technicians to run, which would largely be prohibitive at the global scale. Yet such efforts are underway for coral reefs (Spalding et al. 2016).

One alternative approach are exposure and/or vulnerability indices (Beck et al. 2013, Arkema et al. 2013, USACE 2015), which incorporate the extent and spatial distribution of multiple coastal ecosystems into relatively simple frameworks for coastal hazards (Arkema et al. 2013, Wamsley et al. 2015). While not capturing hydrodynamic and geomorphological processes, such an approach incorporates more readily available data at a global scale, allows for an assessment of change in social benefit through changes in coastal habitats and estimates the marginal role of ecosystems relative to various abiotic variables that have been identified as good indicators of exposure to hazards (e.g., shoreline type, elevation, waves, sea-level rise, Hammar-Klose and Thieler 2001, Wamsley et al. 2010, Arkema et al. 2013).

<u>Landslides</u>

The influence of vegetation is very difficult to measure directly at the scale of a single tree or shrub, though considerable efforts have been made to relate vegetation distribution to the apparent cohesion of a hillslope introduced by root tensile strength (Nilaweera and Nutalaya, 1999; Schmitt et al., 2001; Reubens et al., 2007; Greenwood et al., 2007; Genet, 2008; Vergania et al., 2017). At the watershed scale, linkages between deforestation and increased landslide occurrence in steep terrain have been documented (e.g., Swanson and Dryness, 1975; Dhakal and Sidle, 2004; Johnson et al., 2007). Landsliding is a localized phenomena, so it remains difficult to objectively define direct linkages between vegetation change and landslide occurrence at the global scale. However, linkages between vegetation density and landslides in some locations (Miller and Burnett, 2007) suggests a correlation that could be investigated globally.

<u>Flood Control</u>

Incidence of flooding is widely measured, but direct measurements of the effect of land cover on flooding is limited and relies on robust measurements of floods in watersheds that are comparable save some known difference in land cover (Hewlett 1982). Lacking this information, assessments of the impact of land cover on flood regulation is largely statistical (Van Dijk, Van Noordwijk et al. 2009)

Fire Control
The area burnt by wildfire can be measured using satellite technology such as MODIS imagery, which provide global coverage at ~0.5 km resolution (Justice, Giglio et al. 2002, van der Werf, Randerson et al. 2008). This is inadequate for most management programs due to the coarse resolution and poor detection rates for low intensity fires (including prescribed burns). Therefore, many fire agencies maintain their own fire history mapping derived from finer-scale satellites such as Landsat (Murphy, Cochrane et al. 2015), or from operation mapping of fire boundaries. Estimating the benefit from prescribed burning is essentially a research question, requiring statistical analysis of the feedback of prescribed fire on wildfire (Price and Bradstock 2011) and monitoring of biodiversity (Russell-Smith, Watt et al. 2012).

Tolerable fire intervals are usually applied to plant communities and are a very useful way to measure, map and monitor the fire regime status of the landscape. They are used in several countries to guide fire planning and intervention, especially in protected areas, including South Africa (Rogers 2003) and Australia (Kenny, Sutherland et al. 2004), and they are being considered in the USA (Moritz, Hurteau et al. 2013). Typically, a map will show the areas below threshold (two fires occurring too frequently), within threshold, and above threshold (unburnt for too long).

As with fire history mapping, fire interval analysis is a proxy for landscape health (e.g. of biodiversity or soil), which is often the true objective of fire management, and it is assumed that acceptable intervals actually translate into benefits.

9.3.3. Links to other NCPS

Natural hazards affect ecosystems as well as people, and these changes almost always affect the co-production of NCP in those ecosystems. Hazards can also have direct impact on NCP. For example, reduction in wildfire risk lessens impacts on air and water quality, soils, future hazards, food, and materials.

NCP2 – pollination -
NCP3 – air quality – Fire has a direct impact on air quality
NCP4 – climate – vegetation providing hazard regulation, including coastal vegetation, store and sequester carbon in above and belowground biomass as well as in sediments. Landscape fire influences many climate-related processes, by reducing the albedo of affected land (a warming effect), introducing black carbon into the troposphere (cooling), reducing convection (reduced rainfall), and emitting greenhouse gases (Bowman, Balch et al. 2009). Annual global emissions from biomass burning (landscape fire plus human consumption of biomass) is estimated at about 50% that of fossil fuel emissions (Bowman, Balch et al. 2009).
NCP5 – ocean acidification -
NCP6 – water quantity -Wildfire changes runoff regimes (Smith, Sheridan et al. 2011)
NCP7 – water quality – In nearshore areas, subtidal and coastal vegetation filter out nitrogen, phosphorus and bacteria. Wildfire can influence water quality by removing vegetation and exposing the ground to run-off, soil erosion and the input of nutrients in the ash (Smith, Sheridan et al. 2011).
NCP8 – soils -
NCP10 – pests –
NCP11 – energy -
NCP12 – food – Food-producing areas may be protected by ecosystems. In addition, the hazard-

protecting ecosystems themselves may provide food or feed. Nearshore ecosystems providing coastal protection also provide nursery and adult habitat for economically important fish and invertebrates. A benefit of landscape fire is in the provision of resources for food (i.e. managing vegetation for cropping or forage).agricultural cultivation.

NCP13 – materials –

NCP14 – medicine -

NCP15 – learning – In ancient traditions such as in Australia, burning practices are learned over a lifetime, are governed by complex rules and are highly complex in their planning and execution (Garde, Nadjanerrek et al. 2009). I

NCP16 – experiences - Coral reefs draw millions of tourists for snorkeling and SCUBA diving globally

NCP17 - identities - New research into human health and wellbeing shows importance of blue viewsheds and ocean access for restorative nature and fostering physical activity.

9.3.4. Indicators of NCP (co-) production

NCP	**Production Function**	**Indicator/ Proxy**	**Rationale/ justification for why this indicator/ proxy was selected**	**Data set**
Sub-NCP	From summary bullets		*There's good evidence? It's the easiest? We have the data? The data time series is long enough?*	*URL, citation*
Coastal Protection: Avoided erosion, flooding and wave attenuation , esp. related to influence on long-term wave climate	Width of reef crest, height relative to water level	Coral reefs distribution and extent	There's good data, we have good evidence; not sure about time series	UNEP-WCMC, WorldFish Centre, WRI, TNC (2010). Global distribution of warm-water coral reefs, compiled from multiple sources including the Millennium Coral Reef Mapping Project. Version 1.3. Includes contributions from IMaRS-USF and IRD (2005), IMaRS-USF (2005) and Spalding et al. (2001). Cambridge (UK): UNEP World Conservation Monitoring Centre. URL: http://data.unep-wcmc.org/datasets/1
Coastal Protection: Avoided storm surge, wave attenuation ; sediment retention	Width of buffer in cross shore direction; density, width etc. of roots, trunks, canopy	Mangrove distribution and abundance	There's good data, we have good evidence; not sure about time series	Data Provided By: US Geological Survey (USGS) 1997, 2000 Citation:http://onlinelibrary.wiley.com/doi/10.1111/j.1466-8238.2010.00584.x/pdf
Coastal Protection: Avoided storm surge, wave attenuation ; sediment retention	Width of buffer in cross shore direction; density, width etc. of shoots	Saltmarsh distribution and abundance	There's good data, we have good evidence; not sure about time series	Mcowen C, Weatherdon LV, Bochove J, Sullivan E, Blyth S, Zockler C, Stanwell-Smith D, Kingston N, Martin CS, Spalding M, Fletcher S (2017). A global map of saltmarshes. Biodiversity Data Journal 5: e11764. Paper DOI: https://doi.org/10.3897/BDJ.5.e11764; Data URL: http://data.unep-wcmc.org/datasets/43 (v.4)
Coastal Protection: Avoided storm surge, wave attenuation ; soil erosion	Width of buffer in cross shore direction; density, width etc. of trunks, canopy	Coastal forest distribution and extent	Not sure	Global land use land cover
Coastal Protection: Indirect factor		Globally available combined Bathy/Topo	Role of ecosystems for coastal protection depends on elevation and depth	

Coastal Protection: Indirect factor		Globally available data for waves and wind	Literature shows that influence of ecosystems depends on wave heights	NOAA WaveWatch III data
Coastal Protection: Indirect factor		Globally available continental shelf	Distance from shoreline to edge of the continental shelf is a good indicator of storm surge	A globally available dataset of the continental margins was prepared by the Continental Margins Ecosystem (COMARGE) effort in conjunction with the Census of Marine Life (Arkema et al. 2013)
Fire			fire mapping and analysis of fire intervals are the usual metrics for measuring landscape fire. However, they do not measure the cost or benefit from fire directly so they are proxies.	

9.3.5. Trends in Co-Production

9.3.5.1. General (across all units of analysis)

Coastal Protection

Several recent studies have aimed to assessed coastal protection globally using wave attenuation as a metrics for coastal protection. For corals, Ferrario and colleagues (2014) synthesized data from 27 field studies across the Atlantic, Pacific and Indian oceans and found on average coral reefs provide a 97% reduction in wave energy. Similar syntheses of saltmarsh studies from across the globe found wave attenuation in saltmarshes varied substantially (from about 10-90%) with distance into the marsh and wave height as critical factors (Shephard et al. 2011, Gedan et al. 2011). Koch and colleagues (2009) similarly showed variability and non-linearity in coastal protection services provided by reefs and vegetation. However, for many of the studies compiled in the meta-analyses above, incident wave heights are low (>3 m). Pinsky et al. 2013 re-analyzed existing wave height studies in kelp, marsh, seagrass, and mangrove and found that wave attenuation varies with drag coefficient and that failing to account for a decline in drag under storm conditions could overestimate wave attenuation by 19-1600% in the high hazard context when coastal protection really matters. Thus, larger habitat areas may be needed to provide coastal protection services than originally thought. In the most recent quantitative synthesis of 69 studies of wave attenuation across multiple habitats, Nayaran and colleagues (2016) again find wave attenuation to be highly variable, reporting that on average, coastal habitats reduce wave heights by 35-71%.

The aforementioned lay out the evidence that coastal ecosystems modify nearshore hydrodynamic conditions such as wave attenuation. But they are limited from an NCP perspective because, with the exception of Narayan et al. (2016), they lack a connection between reduction in wave heights (provided by nature – often at a location offshore) to processes that matter to people and infrastructure such as avoided erosion and flooding (Arkema et al. 2017). They also do not provide a comprehensive global assessment. To address this deficiency, The Nature Conservancy, through their Mapping Ocean Wealth Project (Spalding et al. 2016), modeled flood hazards and potential damage costs from four different storm return periods (one-in-10 year, one-in-25, -50, and -100-year storms). They estimated land, population, and built capital ($) flooded across all coral reef coastlines to a 90 meter resolution and examined flooding in cross-shore profiles every two kilometers for all coral reefs globally. They found that small declines in the height of the reef crest allow much more wave energy to pass through to flood coastlines. For one-in-10-year events, storm costs would more than triple with the loss of just one meter in the height of the reef crest. Reefs provide significant benefits even for higher intensity, 100-year events where damages would increase to $219 billion with reef degradation. The countries that may see the greatest annual benefits relative to their GDP include many Small Island Developing States, particularly across the Caribbean (Spalding et al. 2016). The study did not explore trends in coastal protection provided by coral reefs through time nor the status of other habitat types.

Loss of coastal and estuarine habitats suggests an overall downward trend in coastal protection services. However, the suite of techniques recently developed by researchers and practitioners for implementing natural and nature-based approaches is growing (Arkema et. al 2017). Thus, some coastal areas are seeing an increase in the use of nature-based approaches to coastal protection, including oyster restoration (Scyphers et al. 2011), installation of sills to facilitate marsh recruitment and growth (NOAA 2015), mangrove conservation through private protected area programs, and coral reef enhancement by out-planting recruits (e.g., Johnson et al. 2011). At the larger scale, the Netherlands, Belgium, US, and several other countries are increasingly investing in massive planning, restoration, and engineering projects (CPRA et al. 2012, van Slobbe et al. 2012, Temmerman and Kirwan 2015), such as the Dutch's innovative "sand engine" (Stive et al. 2013). In the Caribbean, the government of Belize in 2016 passed the country's first Coastal Zone Management Plan in part to safeguard reefs, mangroves, and seagrass for coastal defense (Arkema et al. 2015). The Bahamian government, in the wake of Hurricanes Joaquin and Matthew, has agreed on more than $3 million loan with the Inter-American Development Bank to invest in mangrove restoration for coastal protection following sustainable development planning that accounted for changes in coastal protection services (Arkema et al. 2017). Throughout the Indian Ocean, nature-based approaches have taken hold, but there is often limited input from science and questionable benefits for people and ecosystems (Feagin et al. 2010, Mukherjee et al. 2010). While in South Africa, stakeholders are engaging heavily in processes to inform coastal resilience planning (Reyers et al. 2015).

While no studies have yet assessed trends in coastal protection services globally, there are a few regional examples of modeling coastal vulnerability through time. New York, United States, provides a case example, showing spatial variability in changes in vulnerability through time, noting in particular the loss of marsh islands in the center of Jamaica Bay placing shoreline areas at increased risk of impacts from coastal hazards (2016).

Summary of NCP trends:

- ***Trend*** (& why): Mostly down, up in some places
- ***Spatial variance*** (& why): Spatial variance is large. Attenuation of hydrodynamic conditions such as wave heights and influence on sediment transport processes varies enormously. Adoption of natural and nature-based approaches to coastal protection services is growing in the US, Europe, the Caribbean and elsewhere but shoreline hardening continues apace elsewhere.
- ***Degree of certainty*** (& why): Medium. Coastal protection provided by ecosystems does work, but its efficacy varies substantially. Also no studies exist that assess coastal protection services globally for multiple sometimes interacting habitats.

Landslides

Generally the study of NCP related to landslide occurrence have focused on vegetation and land use change (Swanson and Dryness, 1975; Glade, 2003; Dhakal and Sidle, 2004; Greenwood et al., 2007; Johnson et al., 2007). Most landslides hazard assessment studies emphasize the physical processes related to landsliding (e.g., Corominas et al., 2014; Iverson et al., 2015). Although some studies have investigated the differences between root strength of difference species or have examined root strength impacts for a given biome (e.g., Schmidt et al., 2001; Reubens et al., 2007; Vergania et al., 2017), there is insufficient evidence to comment on how vegetation influences slope stability differentially across different biomes. In particular, the dual role of vegetation in reducing soil wetness through transpiration and reinforcing slopes through root strength is difficult to isolate from the combined impacts of soil properties and thickness, topographic slope, and hydroclimatic setting on predisposing factors to landslide initiation.

Summary of NCP trends:
- ***Trend*** (& why): Unknown
- ***Spatial variance*** (& why): Probably high
- ***Degree of certainty*** (& why): Low

Flood

The extent to which ecosystems regulate flooding is unclear, but has probably declined. There are no indications of change in upland ecosystem regulation of flooding, though any effect would likely be on small to mid-sized floods and in small watersheds, so it would be difficult to detect (van Dijk and Keenan 2007). However, extensive modification of river channels throughout the world has reduced their ability to control flooding along their length (Schoof 1980). In addition, as more people move into floodplains and fill wetlands (McDermott, Michaels et al. 2015), these areas are no longer able help abate floods. Finally, roads play an important role in flood generation (Eisenbies, Aust et al. 2007), so as roadbuilding expands (Dulac 2013), natural regulation of flooding has probably declined.

Summary of NCP trends:
- ***Trend*** (& why): Declining – more roads, river channel modifications, and fill of wetlands and flood plains
- ***Spatial variance*** (& why): High – flooding is inherently local, though ecosystem changes affecting flooding are happening globally
- ***Degree of certainty*** (& why): Medium – low certainty about upstream ecosystem regulation of flooding, higher certainty about effects of channel modification, roads, and floodplain fill.

Fire

Landscape fire is almost ubiquitous around the world (Bowman, Balch et al. 2009, Krawchuk, Moritz et al. 2009). Although wildfire occurs naturally as a result of lightning, in most fire prone areas of the world people are now the main cause of unplanned ignitions (Liu, Yang et al. 2012, Ganteaume, Camia et al. 2013, Mundo, Wiegand et al. 2013, Price 2015, Syphard and Keeley 2015, Collins, Price et al. 2016), although probably not in the boreal forests (Achard, Eva et al. 2008, Magnussen and Taylor 2012).

Fire weather severity is projected to increase around the world (Flannigan, Krawchuk et al. 2009), and in several regions the increase is already detectible (Westerling, Hidalgo et al. 2006, Clarke, Lucas et al. 2013, Veraverbeke, Rogers et al. 2017). Wildfire activity is expected respond by increasing (Flannigan, Krawchuk et al. 2009, Keywood, Kanakidou et al. 2013). However, the magnitude of change will be variable, and in ecosystems where fire is already limited by fuel availability (arid and most semi-arid zones), increased temperature will probably reduce plant growth and hence fire activity will probably be reduced (Bradstock 2010). This response is further complicated by the possibility that CO_2 enrichment will improve the water use efficiency of plants (Hovenden and Williams 2010). In the Mediterranean, fire is also increasing because of abandonment of traditional land use practices (Duguy, Alloza et al. 2007). These subtleties make prediction of future fire activity difficult.

It is difficult to estimate how much burning was undertaken before modern times, but in savanna ecosystems up to 30% of the vegetation may have been burnt each year (Russell-Smith, Yates et al. 2007, Archibald, Staver et al. 2012). In modern developed countries, prescribed burning is usually carried out by Government agencies with large budgets. Examples of very proactive prescribed burning programs are in the forests of Western Australia where approximately 8% of the forest is burnt per year (Boer, Sadler et al. 2009) and Kruger National Park in South Africa where 21% is burnt each year (Govender, Mutanga et al. 2012). The West Arnhem Land Fire Abatement program (WALFA) is an example where semi-traditional methods have been re-introduced into a large region to improve biodiversity and to reduce overall greenhouse gas emissions from landscape fires (Russell-Smith, Cook et al. 2013). This model of introducing more fire to reduce overall fire impact is spreading around Australia and the world.

Summary of NCP trends:

- ·***Trend*** (& why): Increasing in response to warming earth, though the trend is complex.
- ***Spatial variance*** (& why): High. Fires affect some regions far more than others, and within a region, the actual place that gets affected by fire is highly random and geographically restricted.
- ·***Degree of certainty*** (& why): Medium. Complex interactions between rainfall and fuel growth, CO_2 and fuel growth and feedbacks between fire and subsequent fuel mean that fire activity may decrease in some regions, but these drivers are not well understood.

9.3.5.2. By Units of Analysis

Unit of Analysis	**Direction of arrow**	**Rationale/ justification for why you think this trend is happening**
1. Tropical and subtropical dry and humid forests LUC: Deforestation		Fire: Forest ecosystems (including montaine, deciduous, eucalyptus, tropical rainforest and boreal forests) experience a range of fire frequencies depending on the period of drought event and ignition patterns, ranging from very infrequent (every 400 years for rainforest and northern boreal areas (Archibald, Lehmann et al. 2013)) to frequent (every 20 years for dry eucalypt forest (Price and Bradstock 2011)). Forest fires can be the most intense and destructive of all landscape fires. Landslide: Commercial forestry is known to increase landslide susceptibility in steep terrain and forestry operations are often threatened by landslide hazards.
2. Temperate and boreal forests and woodlands LUC: Deforestation		Fire: Forest ecosystems (including montaine, deciduous, eucalyptus, tropical rainforest and boreal forests) experience a range of fire frequencies depending on the period of drought event and ignition patterns, ranging from very infrequent (every 400 years for rainforest and northern boreal areas (Archibald, Lehmann et al. 2013)) to frequent (every 20 years for dry eucalypt forest (Price and Bradstock 2011)). Forest fires can be the most intense and destructive of all landscape fires. In the coniferous forests of the USA, a recent increase in wildfire area and impact has been attributed to the replacement of traditional prescribed burning with fire suppression which results in fuel build-up in the forests (North, Stephens et al. 2015). The boreal forest may be an exception where deliberate burning was much more restricted than was wildfire. Landslide: Commercial forestry is known to increase landslide susceptibility in steep terrain and forestry operations are often threatened by landslide hazards.
3. Mediterranean forests, woodland, and scrub LUC: Deforestation LUC: Woody encroachment		Fire: Mediterranean ecosystems are typified by flammable shrublands that experience summer drought and consequently some of the most intense, damaging fires (Keeley, Bond et al. 2011). In the Mediterranean, fire is increasing because of abandonment of traditional land use practices (Duguy, Alloza et al. 2007). In the Mediterranean region, which is highly prone to wildfire, prescribed burning was also uncommon and the risk of fire was minimised incidentally via agricultural practices such as orchard management and grazing animals within tree groves, but these practices were progressively abandoned in the 20th century, leading to higher risk of wildfire (Duguy, Alloza et al. 2007, Koutsias, Arianoutsou et al. 2012).
4. Tundra and high mountain habitats		Fire: The only ecosystems that are essentially free of fire are either extremely arid (e.g. Saharan Africa) or extremely cold (Tundra)(Archibald, Lehmann et al. 2013).
5. Tropical and subtropical savannahs and grasslands LUC: Conversion to cropland LUC: Afforestation		Fire: Savannas in Australia, South America and particularly Africa are the most fire prone with 30-50% of the landscape burnt each year (Archibald, Scholes et al. 2010, Price, Russell-Smith et al. 2012), due to plentiful rain and warmth accompanied by annual drought. It is difficult to estimate how much burning was undertaken before modern times, but in savanna ecosystems up to 30% of the vegetation may have been burnt each year (Russell-Smith, Yates et al. 2007, Archibald, Staver et al. 2012).
7. Drylands and deserts		

LUC: Overgrazing and vegetation removal (?)		Fire: In arid and semi-arid ecosystems, fire is limited to periods following rainfall which provides the plant growth for fuel. The only ecosystems that are essentially free of fire are either extremely arid (e.g. Saharan Africa) or extremely cold (Tundra)(Archibald, Lehmann et al. 2013).
11. Cryosphere		Fire: The only ecosystems that are essentially free of fire are either extremely arid (e.g. Saharan Africa) or extremely cold (Tundra)(Archibald, Lehmann et al. 2013).
Urban coastal		Some urban coastal areas are more prone to landslide occurrence, particularly due to coastal bluff erosion. However, it is unclear whether as a whole coastal areas are more or less susceptible to landslide hazards.
Urban inland		Some inland urban areas are more prone to landslide occurrence, particularly along road cuts and embankments. However, it is unclear whether as a whole inland areas are more or less susceptible to landslide hazards.
Rural coastal		Some rural coastal areas are more prone to landslide occurrence, particularly due to coastal bluff erosion. However, it is unclear whether as a whole coastal areas are more or less susceptible to landslide hazards.

9.4. Impacts on good quality of life

9.4.1. Different types of value

9.4.1.1. What is the NCP contribution

The impacts of hazards are frequently organized into categories: mortality and morbidity; property damage; disruption to lives and livelihoods, including supply chains; reduced feelings of security; and costs of protection and adaptation. Nature can contribute to the reduction of all of these impacts.

Mortality and morbidity

Death associated with natural hazards is most commonly caused by drowning (Ohl and Tapsell 2000). Short term morbidity is the result of both injury and illness, including asthma, gastrointestinal illness, and mental health symptoms, that stem from disaster-related impacts (Fewtrell and Kay 2008). Long term adverse impact of hazards include exposure to contaminants, mold, and toxic substances (Ohl and Tapsell 2000, Fisk, Lei-Gomez et al. 2007).

Property damage

Rebuilding public and private infrastructure is costly and varies enormously based on socio-economic and environmental conditions (Leal Filho 2015).

Disruption

Disruption includes business interruption and damages to a wide array of non-structural assets. Property damage to roads and transport infrastructure may make it difficult to mobilize aid to those affected or to provide emergency health treatment and food and water. Damages also affect short and long-term economic functioning inside and beyond affected areas via supply chain connections. Impacts to power generation and transmission have wide ranging effects caused by the loss of power. Related issues may include water supply and water treatment, resulting in loss of drinking water or severe water contamination, directly impacting human health and business functioning.

Feeling of security

Concern about the potential impacts of hazards, including a feeling of safety and protection of a way of life, has a variety of impacts and may be long-lived. Following flooding events, the majority of people felt tense and ill and needed months and possibly years to recover after the event (Ohl and Tapsell 2000). In the 1998 floods in the UK, the main impacts of recovery disruption resulted from: having to leave home; lack of practical and emotional support; lack of advice on what to do; problems in dealing with insurers and builders; stress from living in damp and damaged properties; and increased financial worries (Tapsell et al., 1999). The loss of memorabilia and sentimental possessions often causes acute distress; this loss may undermine people's sense of self identity and place identity (Baan and Klijn 2004).

Hazards and feelings of security may also affect how people how people organize their lives and livelihoods. Floods can make people feel uneasy and cautious about live along rivers (Baan and Klijn 2004). However if hazards are integrated into people's way of life, they may not have feelings of concern. People living in the floodplains who are more familiar with flooding and better prepared may feel less threatened (Baan and Klijn 2003).

Protection and Adaptation cost

Protection from natural hazards generally includes: man-made infrastructure, semi-natural infrastructure, natural ecosystem. All cost money to build and maintain. Costs of built and semi-natural infrastructure include physical construction of the structure and the costs associated with maintaining it including labor and technology (Leal Filho 2015). Costs of natural infrastructure include the opportunity cost of alternative development. Natural infrastructure is more likely to have ancillary benefits which may offset costs. Adaptation measures are generally grouped into two main sectors: infrastructure and prevention preparedness, usually training and education, which include the cost of motivating residents to cope effectively (Zaalberg, Midden et al. 2009).

Specific services:

For coastal protection services, impacts on quality of life are often defined in two primary ways: avoided property damage and reduction in risk to coastal communities, which can serve as an indicator of reduction in morbidity and mortality and in disruption of lives and livelihoods, especially for those demographics that have less ability to cope with coastal hazards (USACE 2015, Wamsley et al. 2015, NSTC 2015, Arkema et al. 2017).

For landslides, impacts are generally evaluated as morbidity and mortality, property damage, disruption to livelihoods, and limitations in habitability and economic development in steep terrain (Highland and Bobrowsky, 2008; Petley, 2012). Estimates of fatalities and damage associated with landslides are typically assessed for the subset of hydrologically triggered landslides (U.S. Geological Survey, 2004; Petley, 2012), whereas damage from co-seismic landslides as well as landslides associated with volcanic eruptions are typically lumped together with the broader natural hazard event.

Flood impacts include damage to property, human morbidity and mortality, disruption of services, and general trauma (Merz, Kreibich et al. 2010) (Cann, Thomas et al. 2013) (Alderman, Turner et al. 2012). Flooding is the predominate cause of death associated with natural hazards, with most deaths caused by drowning (Ohl and Tapsell 2000). Injury and illness are common impacts, as is exposure to contaminants, mold, and toxic substances carried into or exposed in homes (Ohl and Tapsell 2000, Fisk, Lei-Gomez et al. 2007, Fewtrell and Kay 2008).

The impact of landscape fire is very varied. Naturally occurring fire produces benefits as well as negative impacts. The disturbance caused by landscape fire is an important driver of vegetation dynamics, maintaining a diversity of successional stages across the landscape (Clements 1936, Whelan 1995). This affects the range and amount of natural resources available to people. For example, the flush of new grass growth immediately after a fire that is important for grazing animals and hence hunting or husbandry.

Prescribed burning may be done for a variety of objectives, including for hunting (the fire drive), to promote new grass growth for herbivores, to aid travel, to open up campsites or hunting areas, or to protect fire sensitive vegetation from wildfire. For example, traditional practices in Arnhem Land Australia includes at least 20 purposes for burning, including the general practice of fuel reduction (Garde, Nadjanerrek et al. 2009). It is useful to distinguish two broad types of objectives: those that maintain natural vegetation in the landscape (such as the Arnhem Land example) and those where fire is used to remove vegetation to allow for agriculture (for example, slash and burn agriculture), which is generally a more contemporary phenomenon (Dull, Nevle et al. 2010, Bowman, Balch et al. 2011). Burning for agriculture has a larger negative effect on the likelihood of future wildfire.

In ancient traditions such as in Australia, burning practices are learned over a lifetime, are governed by complex rules and are highly complex in their planning and execution (Garde, Nadjanerrek et al. 2009). In more modern traditions, burning is less structured and focused on pasture maintenance, such as in African savannas (Archibald, Staver et al. 2012).

9.4.1.2. How do we measure contribution?

Evaluating the contribution of nature to reducing the occurrence of a hazard or the impact of a hazard is more difficult than simply measuring the frequency or impact of the hazard. Approaches are frequently statistical to allow comparison among places affect by a hazard that do and do not have nature’s protection.

Mortality and morbidity
Measurements of mortality and morbidity are evaluated in places with different contributions of nature while controlling for influencing factors including hazard type and size, elevation, and vulnerability of the population. In the wildland urban interface, the benefit of prescribed burning should be measured as the reduction in life and property damage achieved, but this is very difficult to estimate. There are current research projects that aim to quantify the improvement (or otherwise) in air quality that prescribed burning programs achieve (Williamson, Bowman et al. 2016).

Avoided property damage
Expected impacts of hazard events are often calculated based on relationships between hazards and damages. For flooding, for example, generalized depth damage curves are used when available. Avoided damages provided by natural and nature based features are then quantified as a function of the change in flood depth during a storm event and therefore the expected associated impacts using an expected damage function approach [98, 138, 140] However, these functions are based on local building codes and structure design, so depth-damage relationships are geographically specific[144] and only available in a handful of countries (i.e., the U.S., Australia, Germany, the Netherlands, and the U.K.[145] Moreover, monetary valuation can understate the importance of protection services for highly vulnerable communities when property values are low (NSTC 2015).

Disruption
The number of people displaced (including demographic characteristics) and types of facilities affected by coastal hazards (e.g., schools) offer alternative metrics for valuing impact of coastal protection services. Examining multiple metrics of social vulnerability helps give a more complete picture of which demographics are benefiting from risk reduction provided by coastal protection services. An alternative to depth-damage curves is an exposure/consequence of social vulnerability framework.

Feeling of security
Community vulnerability studies generally focus on demographic factors that influence the ability of populations to prepare for, respond to, and recover from coastal hazards.[100, 154] Differences in access

to resources (knowledge, technology, monetary), power (political power and representation), capacity (social, physical, transportation), and information are major elements driving disparities in disaster response.[100-101, 104, 150, 154, 160] Several key factors are important indicators for these larger concepts, including race/ethnicity, gender, education, income and poverty, age, and housing characteristics.

Protection and adaptation cost

Cost of building protective infrastructure is generally known; savings based on natural infrastructure are usually modeled based on reduced demand for built infrastructure. Adaptation cost can be also estimated using risk models combined with hazard maps and vulnerability maps of an specific area (Zhou, Mikkelsen et al. 2012). The West Arnhem Land Fire Abatement program estimates greenhouse gas emissions from prescribed and wildfires and compares annual values to a benchmark period before the program commenced (Russell-Smith, Cook et al. 2013).

9.4.1.3. Substitutability

People can substitute for hazard mitigation NCP both by changing the impact of the hazard (e.g., blocking it with built infrastructure) or by removing themselves and their property from impacted areas. NCP can also be substitute by changing the damage function from the hazard, such as by increasing drainage, reinforcing structures, or manually reducing fire fuel loads.

Substitutes for coastal protection include hard infrastructure approaches to preventing erosion and flooding such as bulkheads, seawalls, rockwalls, jetties, and levees (citations). They also include other strategies such as setback distances which demarcate a distance from the shoreline beyond which all infrastructure must be built in order to reduce exposure. More recently, people are increasingly interested in “living shorelines” which include both natural features such as an existing reef and man-made nature-based features such as a restored oyster reef. Some of these structures are hybrid approaches such as restored saltmarsh fronted by a small rock sill.

For landslides, geotechnical engineering substitutes include measures to enhance drainage and reinforce slopes. In many cases these can be more effective over human time scales for enhancing slope stability and reducing landslide occurrence. However, the cost of engineering solutions is often prohibitive.

To substitute for NCP that reduce flood impacts, man-made infrastructure such as levees, channel straightening, and bank armoring can reduce flood risk. However, they can fail in a variety of ways. When effective, flood-control infrastructure can exacerbate flooding downstream, transferring impacts to other communities (Bechtol and Laurian 2005). Improvements in urban drainage infrastructure can also substitute for flood-reducing NCP (Arnbjerg-Nielsen and Fleischer 2009).

In terms of managing risk to people from fire, prescribed burning is only one of many strategies that include fire suppression (usually the largest cost to fire agencies), mechanical fuel treatments, and improving the fire-resistance of the built environment.

9.4.1.4. Status and Trends in impact (value)

Coastal Protection

A few studies have begun to link the supply of coastal protection services with demographic metrics reflecting social vulnerability to hazards (Arkema et al. 2013, Beck et al. 2013, Liquete et al. 2013, Canick et al. 2016). These include a report assessing the potential for marsh to provide protection to vulnerable people and property around Long Island Sound now and under future sea-level rise scenarios (Beck et al. 2013). Another paper from the same year showed that coastal habitats may be playing an important role in reducing the number of poor families at high risk in southern Texas and the number of elderly at high risk in Florida (Arkema et al. 2013). Furthermore, Liquete and colleagues (2013) mapped coastal protection as an ecosystem service in Europe, considering natural exposure, capacity (including the presence of habitats), and human demand.

Data from several hundred villages in Thailand were used to test the influence of mangroves on mortality from a 1999 super cyclone (Das and Vincent 2009). After controlling for several factors that influence the relationship between vegetation and coastal protection (i.e., elevation), researchers found that villages with wider mangroves experienced statistically significant few deaths than those villages with narrower or no mangroves.

Coastal protection provided by coral reefs In the Turks and Caicos Islands is valued at US$16.9 million per year, in contrast to the cost of using hard-engineering options (dykes and levees) for coastal protection which has been estimated at 8% of its gross domestic product, or US$223 million. In another example, wetlands of the Mississippi Delta provide services worth US$12 billion–47 billion per year. If the wetlands of New Orleans were to be restored and used as part of the coastal defense system, the estimated cost would be: for marshland stabilization US$2 per square metre for marshland stabilization; US$4.30 per square meter for marshland creation; and US$14.3 million for freshwater diversion. In contrast, the cost of engineering solutions for coastal defense in the Gulf of Mexico region is high. To heighten a dyke by 1 m costs between US$7 million and US$8 million per kilometer. To heighten concrete floodwalls costs between US$5.3 million and 6.4 million per linear kilometer. To heighten closure dams (in water) 1 m costs US$5.3 million per kilometer. To armor levees for each square meter costs between US$21 and US$28 (Jones et al. 2012).

<u>Landslides</u>

Only a few studies directly address the potential economics of the NCP associated with reduction in landslide occurrence (Collison and Anderson, 1996; Moos et al., 2015). Whereas human encroachment into landslide prone areas may as a whole increase the potential for humans to be exposed to landslides, improved education about landslide hazards and engineering works to mitigate losses may at the same time be reducing the exposure.

<u>Flooding</u>

People have frequently settled beside rivers and streams for the water, transport, and other benefits they provide, but this also creates susceptibility to flood impacts (Jha, Bloch et al. 2012). That susceptibility is exacerbated because poor and vulnerable people are disproportionately likely to live in floodplains and be affected by flooding (United Nations Human Settlements Programme 2003)

Health impacts of flooding are substantial (Alderman, Turner et al. 2012), and about 10 to 20 thousand human lives are lost to flooding each decade (Jha, Bloch et al. 2012). The cost of global reported flood damage has increased by more than 50-fold over the past 5 decades to between $150 and $200 billion USD in the 2000s (Jha, Bloch et al. 2012).

<u>Fire</u>

Wildfire and prescribed fire have strong geographic patterns which affect different people. In most countries, urban populations are insulated from the negative and positive effects of fire, though they can experience severe smoke pollution (Johnston, Henderson et al. 2012) and fires have occasionally burnt into cities (Chen and McAneney 2004). Impacts on life and property are more common at the wildland urban interface, which occurs around cities and towns around the world . The benefits from promoting pasture growth occur in extensive rangelands in all continents, with low population density. Traditional burning practices where fire is used for a variety of resource and cultural purposes is relatively rare in modern times, and is probably most preserved in northern Australia

(Yibarbuk, Whitehead et al. 2001). The use of fire to clear land for agriculture is still prevalent in tropical parts of Asia and can be responsible for massive air quality impacts (Jayachandran 2009).

9.4.2. Indicators of NCP impact

9.4.2.1. Indicators by value

Value type	Indicator/ Proxy	Rationale/ justification for why we this indicator/ proxy was selected	Data set	Scale of Measure – space	Scale of measure - time
Morbidity	Thousands of deaths each year	Reasonably well documented the number of deaths per year in the developed and developing world	*Petley et al*	Global	Year ranges
Direct economic losses	Billions each year	Poorly documented and based on outdated estimates needs to be revisited in future research	USGS, 2004	USA	1970's
Indirect economic losses	Unknown	Unknown, but indirect losses related to landslide occurrence likely as great or greater than direct losses. Very difficult to assess at any scale.	No data	None	????
More habitable planet	Unknown	The threat of landslides impairs habitability of locations where steep topography and precipitation coincide, and likely prevents some areas from being more developed by humans and/or limits the number of humans willing to live in landslide prone areas	No data	None	???
Mortality	Fraction of people die due to flood				
Morbidity	Fraction of people infected with disease of flood				
Mental health	post-traumatic stress disorder score; cumulative exposure indicators (Verger, Rotily et al. 2003) Psychological health indicators (Tapsell and Tunstall 2008)				
Property damage	direct tangible damage loss				
Ecosystem damage	Landscape inundated by the flood				
Disruption	Absolute damage to roads and transportation, power plant,				

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9.5. Summary

Responding to and attempting to manage natural hazards is a longstanding part of human existence, and hazards occur regardless of the state of nature. However, ecosystem characteristics can help manage the occurrence and impact of hazards, and human activities like proscribed burning are an example of the co-production of this NCP.

Many of the changes in nature over the past 30 years, ranging from conversion of coastal mangroves to increased roadbuilding in mountains to reducing natural forest fires, have reduced the ability of ecosystems to mitigate hazards and their impacts. These changes have occurred in tandem with climate change, which is increasing hazard frequency and intensity.

Responding to the expense and fallibility of built interventions to reduce the risk and impact of hazards, nature-based interventions are becoming more common. Thought the extent of these interventions remains small relative to boht built infrastructure and other change in nature that have reduced hazard mitigation, they indicate an important positive trend.

Increasing population has increased the number of people susceptible to hazards, particularly because people often settle in hazard-prone locations such as cities in low-lying and flood-prone areas and settlements in coastal flood zones and fire and landslide-prone mountains. Many of the people most susceptible to the impacts of hazards are poor, elderly, discriminated against, or otherwise vulnerable populations. In large part, this is because particularly hazard-prone areas are likely to be less costly to live in, reflecting their history of hazard impact (United Nations Human Settlements Programme 2003).

	Potential Nature's Contributions	**Output of the joint production**	**Impact on good quality of life**
Indicator	Lowered incidence and impact of hazards Floods: lowered flood peaks Fires: lowered fuel load Coastal: protection Landslides: stabilization	Incidence of hazards	a) Reduced morbidity and premature mortality b) Reduced property loss
Trend During the last 50 years: 2 = Major increase (>20%) 1 = Increase (5% to 20%) 0 = No change (-5% to 5%) -1 = Decrease (-20% to -5%) -2 = Major decrease (< -20%)	**-1** Increasing conversion of landscapes that buffer hazards, including shoreline hardening, floodplain development, and detrimental forest management. (Renaud, Sudmeier-Rieux et al. 2013)	**-2** Number of hazards have been increasing over time (Guha-Sapir, Hoyois et al. 2016) (Van Aalst 2006)	a) -2 number of people impacted increasing over time (Guha-Sapir, Hoyois et al. 2016) b) -2 property impacted increasing over time (Guha-Sapir, Hoyois et al. 2016)
Spatial variance 3 = opposite trends in different regions 2 = same directional trends in different regions but of contrasting magnitude	3 Most land use change has reduced hazard occurance, but in some places peopel are	2 The number and location of disasters varies substantially year to year, but trends are all	a) 2 b) 2 Impact is increasing everywhere, but less-developed countries and those

1 = similar trends all over the world	specifically investing in NCP to reduce hazards (Renaud, F. G., et al. 2013) (Arkema, K. K., et al. 2017).	towards more disasters (Guha-Sapir, Hoyois et al. 2016).	with less robust institutions tend to be more affected by disasters (Kahn 2005).
Variance across user groups 3 = opposite trends for different groups 2 = same directional trends for different groups but contrasting magnitudes 1 = similar trends for all social groups	NA	NA	a) 2 b) 2 Population in vulnerable areas, such as along coasts and in fire-prone areas, has been increasing. Hazards have a greater impact on more vulnerable social groups (United Nations Human Settlements Programme 2003).
Degree of certainty 4 = **Well established**: Robust quantity and quality of evidence & High level of agreement 3 = **Established but incomplete**: Low quantity and quality of evidence & High level of agreement 2 = **Unresolved**: Robust quantity and quality of evidence & Low level of agreement 1 = **Inconclusive**: Low quantity and quality of evidence & Low level of agreement	2 Mechanisms reasonably well understood, but actual and potential impact of NCP still poorly studied (Renaud, F. G., et al. 2013)	3 Hazard occurrence is well studied (Guha-Sapir, Hoyois et al. 2016)	a) 3 b) 3 Hazard occurrence and impact is well studied, but less information tying reduction in impact to nature (Renaud, F. G., et al. 2013) (Guha-Sapir, Hoyois et al. 2016)
Two to five most important papers supporting the reported trend	Renaud, F. G., et al. (2013). The role of ecosystems in disaster risk reduction, United Nations University Press. Arkema, K. K., et al. (2017). "Linking social, ecological, and physical science to advance natural and nature-based	Guha-Sapir, D., et al. (2016). Annual Disaster Statistical Review 2016: The Numbers and Trends. Brussels, CRED. Van Aalst, M. K. (2006). "The impacts of climate change on the risk of natural disasters." Disasters **30**(1): 5-18.	Kahn, M. E. (2005). "The Death Toll from Natural Disasters: The Role of Income, Geography, and Institutions." The Review of Economics and Statistics 87(2): 271-284. United Nations Human Settlements Programme (2003). The Challenge of

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9.6. Search methodology

The following searches were used in the initial screening, and some additional references added based on the authors knowledge of research in this field.
→ “meta analysis review landslides” (note: generally the term meta-analysis led to a lot of biology papers without any relevance to landslides)
→ “review landslides”
→ “review landslide susceptability vegetation”
00> review landslide susceptibility deforestation
→ “review landslide susceptibility burrowing”
→ “review landslide susceptibility grazing”

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10. NCP10: Regulation of organisms detrimental to humans

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10.1. IPBES Definition:

Regulation, by ecosystems or organisms, of pests, pathogens, predators, competitors, etc. that affect humans, plants and animals, including e.g.:
. Regulation by predators or parasites of the population size of non-harmful important animals (e.g. large herbivore populations by wolves or lions)
. Regulation (by impediment or facilitation) of the abundance or distribution of potentially harmful organisms (e.g. venomous, toxic, allergenic, predators, parasites, competitors, disease vectors and reservoirs) over the landscape or seascape
. Removal of animal carcasses and human corpses by scavengers (e.g. vultures in Zoroastrian and some Tibetan Buddhist traditions)
. Regulation (by impediment or facilitation) of biological impairment and degradation of infrastructure (e.g. damage by pigeons, bats, termites, strangling figs to buildings)

10.2. Why is this NCP important?

The provisioning (food and fibre) services of agroecosystems depend on a range of supporting and regulating services such as pollination and biological control (the natural regulation of pests, weeds and diseases)(Bianchi et al., 2006; Zhang et al., 2007; Sandhu et al., 2010). However, agriculture also receives dis-services in the form of competition for water and space, or damage to crops from herbivores and diseases (Zhang et al., 2007). One of the principal tasks of farm and landscape managers is to reduce the impact of dis-services usually through soil and water management (flooding, ploughing, burning or rotavating) or by applying pest management options such as pesticides, traps or barriers (Oerke et al., 2004; Horgan 2017). Recently, there has been an increase in research attention to the benefits of natural pest regulation and the need to promote essential pest regulating services to more effectively counter ecosystem dis-services (Sandhu et al., 2010; Gurr et al., 2016; Horgan et al., 2017).

Control of insect pests by their natural enemies is a critical ecosystem service in agricultural systems. Agricultural pests (including insects, pathogens, and weeds) are responsible for the loss of 37% of all potential crop production (Pimentel 1997). Of 6 major food crops, losses caused by insects alone account for 8-15% of potential production (Oerke 2005). The global cost of invasive insects to agriculture is estimated at US$25 billion per year (Bradshaw et al. 2016), and global expenditures on pesticides exceed US$58 billion per year (Chen 2017). The use and misuse of these chemical controls has often exacerbated pest problems, as pests evolve insecticide resistance (Turcotte et al. 2016) and non-target effects on natural enemies elicit pest resurgence (Settle et al. 1996).

Crop losses would be far higher without natural controls. Pimentel (2005) estimated that at least 50% of the control of pest species is due to natural enemies. Losey and Vaughan (2006) estimated the number at 65%, which translated to US$4.5 billion in avoided crop damage. Yet this invisible and essential service for agriculture is under threat, not just from increased pesticide use that often harms natural enemies even more severely than the intended pest targets (Theiling and Croft 1988), but also from agricultural intensification and loss of diversity in farming systems, at landscape and local scales.

10.3. (Co-) production

10.3.1. How is this NCP produced?

1) Regulation of pests and pathogens that affect plant crops

Ecological processes that support the regulation of crop pests are predation, parasitism and infection by a wide range of micro- and multicellular organisms (especially arthropods). Crop pathogens are regulated by predators (most commonly nematodes), competitive microbial agonists that operate by the production of antibiotics and other mechanisms, and parasites. Though crop pests and pathogens are often strongly affected by abiotic conditions such as temperature and humidity, the foregoing biotic factors can provide very significant additional population regulation. Empirical evidence from this comes from the practice of biological control in which these processes are manipulated. Biological control has been pursued scientifically for over a century, producing many examples of target pest suppression, yet has roots in traditional agricultural practices.

There are many ecological processes that are important to crop pest and pathogen regulation. For insect pests, biological control by natural enemies such as predators and parasitoids helps to regulate their populations and prevent catastrophic outbreaks. Biological control can be enhanced on farms by enhancing plant diversity and providing SNAP resources, which include Shelter, Nectar, Alternative prey, and Pollen that enhance natural enemy abundance and diversity, and help to control pests (Letourneau et al. 2011, Gurr et al. 2017). Habitat diversity at the landscape-scale, with many different crops and non-crop habitats integrated together, can also enhance biological control and contribute to pest regulation (Chaplin-Kramer et al. 2011). Bottom-up regulation of insect pests, whereby plants themselves contribute to pest control is also an important means of pest regulation. Plants contain an array of physical (e.g thorns and trichomes) and chemical defenses (e.g. terpenoids and alkaloids), which are constitutive or can be induced by exposure to insect pests and can directly reduce herbivory, attract natural enemies to enhance biological control, or even induce resistance in other plants (Mithöfer and Boland 2012, Mauch-Mani et al. 2017).

Natural and semi-natural habitat in agricultural landscapes can support natural enemies by providing habitat for reproduction or overwintering, alternate prey, and floral resources (Landis et al. 2000). Thus, several quantitative reviews and meta-analyses have concluded that natural enemy abundance, diversity, and activity (predation, parasitism) increase with landscape complexity or the proportion of surrounding non-crop habitat (Bianchi et al. 2006, Chaplin-Kramer et al. 2011, Holland et al. 2017). This positive response does not necessarily confer adequate pest control, as there is no evidence that greater landscape complexity reduces pest abundances (Bianchi et al. 2006, Chaplin-Kramer et al. 2011). However, many environmental and farm management factors contribute to pest abundance, and the ecosystem service of natural pest control might best be defined as suppression of pest population growth, or the difference between pest population size with and without natural enemies.

Analyzing ecological succession is relevant to understand how regulation of organisms detrimental to humans is produced. Ecological succession tends to drive crops and managed landscapes toward more complex but stable successional climaxes (Horgan 2017). For example, a range of herbivore that damage the leaves of cereal or vegetable crops will open spaces in the canopy that allows light penetration for the germination and growth of weeds; weeds in turn provide accessible food in the form of weed seeds for granivorous birds and rodents and perches from which granivores can feed on cereal grains (Drost and Moody 1982; Rodenburg et al., 2014; Horgan 2017). Note that in this example of ecological succession, herbivores and diseases are themselves regulators that naturally respond to high densities of crop plants with relatively low genetic variability and poor anti-herbivore defenses (Brown 2002; Koricheva 2002). In most cases, farmers make their greatest efforts to delay succession during the vulnerable crop establishment stages where competition for light, space and nutrients between crop plants and weeds is most intense (Poole and Gill 1987; Glen 2000;

Savary et al., 2005). Therefore, ecological processes that act at early stages in succession to promote crop survival, but delay competitors such as weeds or defoliator pests play a large role in supporting food provisioning, particularly in annual crops (Settle et al., 1996; Birkhofer et al., 2008; Baraibar et al., 2009). Advanced stages of succession are seldom reached during the crop life-cycle (soften only occurring after field abandonment by farm managers). This is mainly due to cropping designs that have built-in competitive superiority or allelopathy against weeds, or plant defenses derived from crop ancestors – often developed over millennia (Altieri 1999; Reynolds et al., 2009), and because of efficient regulation of weeds, herbivores and diseases by natural enemies. For example, during crop establishment, granivorous carabid beetles and ants remove large quantities of weeds seeds from the soil surface, herbivorous caterpillers and molluscs reduce weed biomass and seed-feeding beetles and moths reduce the reproductive output of weeds (Dirzo 1980; Brust 1994; Baraibar et al., 2009; Van Driesche and Hoddle 2009). Furthermore, predatory birds and mammals can reduce rodent damage either by causing direct mortality of rodents (Hafidzi and Na Im 2003; Rao et al., 2009), or by creating a landscape of fear that prohibits rodents from accessing crop fields (Jones et al., 2017).

Evidence for the contribution of regulatory ecosystem services to people is perhaps most apparent when that regulation breaks down. The breakdown of regulation is often caused by the mis-management of crops and landscapes, the disassociation of herbivore from their natural enemies as in the case of invasive herbivores, or the deliberate removal of natural enemies through hunting or collecting. For example, outbreaks of herbivores such as insects and mites frequently result from the depletion in natural enemies due to the overuse of chemical insecticides (Hardin et al., 1995; Cuong et al., 1997; Horgan 2017). Invasive weeds and herbivores can attain sustained high densities in newly invaded regions due to the absence of natural enemies in the invaded range (Mitchell et al., 2003; Kenis et al., 2009; Yamanishi et al., 2012). The introduction of natural enemies in classical biological control will often reduce densities to non-damaging levels, clearly indicating the role and benefits (that are often unperceived) of natural enemies in regulating herbivores in their native ranges (Hajek et al., 2007). In many cases, very few (and sometimes only one) natural enemy species is required to reduce sustained post-invasion outbreaks (Roland and Embree 1995; Hajek et al., 2007); however, a suite of natural enemies that includes both specials and generalists may be necessary to ensure resilience (the time required for outbreaks to return to lower, equilibrium densities)(Roland and Embree 1995). The elimination of apex predators from farmlands can release herbivores, including mammals, birds and arthropods that cause crop damage (Richie et al., 2012). Campaigns to reintroduce predators using owl boxes or to augment vertebrate predators such as fish have been attempted in various crops and regions (Hafidzi and Na Im 2003; Sin 2006). A similar situation arises when field crops are caged to exclude predators; for example, high densities of herbivores develop in caged rice in tropical Asia, while outside the cages herbivores are regulated by a diversity of natural enemies and herbivore densities remain low (Kenmore et al., 1984).

To ensure efficient pest regulation, natural enemies must be maintained in or near the crop during periods when herbivore densities are low, and should react to periods of increased herbivore density through behavioural (shifts in feeding preferences) or numerical (aggregation to patches with high herbivore numbers or increased reproduction in patches with high herbivore densities) responses (Murdoch 1994). For specialist natural enemies such as egg parasitoids, the field habitat or agricultural landscape should promote landscape complementation (individuals move through the landscape to make use of non-substitutable resources), whereas generalist predators, such as birds, spiders and predatory beetles are likely to depend more on landscape supplementation (individuals move through the landscape to make use of substitute resources)(Dunning et al., 1992; Taylor et al., 1993). The appropriate scales required for complementation and supplementation are largely unknown, although several studies used field-scale or farm-scale manipulations of habitat to successfully enhance the services of specialist parasitoids (Bianchi et al., 2006; Horgan et al., 2016;

Gurr et al., 2017). Efficient responses by natural enemies will reduce the impact of perturbations during crop production, such as during nutrient pulses caused by fertilizers applications (De Kraker et al., 2000), during the physiological resurgence of herbivores due to insecticides or other pesticides (Cuong et al., 1997), or during times when weather conditions are optimal for herbivore reproduction and development (Kiritani 1999).

Traditional agricultural systems, typically have high levels of botanical diversity (with diverse crop species often grown in small plots amid non-crop vegetation), low use of synthetic inputs (especially pesticides), and low levels of soil disturbance. These factors favour the operation of natural regulation of crop pests and pathogens but farmers have long sought to manipulate the activity of beneficial species to provide higher levels of nature's contributions to people (NCP). An oft-cited example is the movement of ant nests to locations where additional pest control is desired, or the placement of bamboo poles between orchard trees to facilitates ant foraging (ref).

There are similarities and differences in the ecological processes that regulate crop pathogens and insect pests. Biological control and plant defenses are also both important in pathogen regulation. Biological control may contribute to regulating insect-vectored plant viruses by reducing vector populations (Long and Finke 2015). There are also examples of natural enemies controlling soil borne pathogens such as predatory fungi that can entrap nematodes (Su et al. 2017) and some fungal pathogens (Ownley et al. 2010). As with biological control of insect pests, enhancing crop diversity can increase pathogen regulation (Boudreau 2013), though the effect is often attributed to the dilution of susceptible hosts rather than control by natural enemies (Ostfeld and Keesing 2012). In contrast with biological control of crop pests, the impacts of mixing crop cultivars on suppressing pests has received relatively more study in crop pathogen systems (Grettenberger and Tooker 2015), while there is relatively little known about how landscape-scale diversity affects pathogen regulation (Claflin et al. 2017). Similar to insect pest control, plants can directly regulate pathogens via a wide array of defensive chemistries that are constitutive or can be induced by exposure to insect pests, pathogens, or even beneficial microbes (Mysore and Ryu 2004, Mauch-Mani et al. 2017). Additional ecological processes that seem to be more important in crop pathogen regulation than insect pest regulation include symbiosis and competition. Beneficial Pseudomonas spp, Trichoderma spp. and Mycorrhizal spp. can form symbiotic relationships with plants and can induce systemic resistance and defense priming against pathogens (Mauch-Mani et al. 2017). Some soils can also be generally suppressive to disease, which is often attributed to a high abundance and diversity of microorganisms that outcompete pathogens for soil carbon resources (Larkin 2015, Schlatter et al. 2017).

There are general trends in ecological insect pest regulation that have been identified. Diverse and even natural enemy communities tend to provide relatively high levels of biological control (Letourneau et al. 2009, Crowder et al. 2010). Increasing plant and habitat diversity tends to conserve natural enemy species and promote biological control, though impacts on pest populations themselves tend to be more variable. Intercropping with multiple plant species has been shown in numerous reviews to increase densities of natural enemies (Letourneau et al. 2011, Dassou and Tixier 2016), and to reduce insect pest levels (Letourneau et al. 2011, Iverson et al. 2014), especially for specialist herbivores (Andow 1991, Dassou and Tixier 2016). On-farm conservation biological control strategies such as wildflower strips, hedgerows, and woodlots have been shown to increase natural enemy populations fairly consistently (Letourneau et al. 2011, Shackelford et al. 2013, Holland et al. 2017), though impacts on pests themselves are less clear (Haaland et al. 2011, Holland et al. 2017). Landscape-scale habitat diversity, with relatively small fields and non-crop habitats integrated within the dispersal ranges of insects, also tends to increase natural enemy abundance and activity (Chaplin-Kramer et al. 2011, Shackelford et al. 2013, Veres et al. 2013), but tends to only regulate insect pest species that overwinter in crop habitats (O'Rourke et al. in prep). Mixing different crop cultivars that exhibit varying levels of intrinsic resistance to insect pests is an emerging area of research that has shown promise for reducing pests such as wheat aphids (Shoffner and Tooker 2013, Grettenberger and Tooker 2015). Some crop cultivars also release volatile chemicals that can repel or attract pests, and these differences in plant chemistries have been exploited to manage pests of field and horticultural crops (Cook et al. 2007, Letourneau et al. 2011).

Biodiversity at different scales has also been shown to support the regulation of crop pathogens. A meta-analysis examining the effects of genotypically diverse crop mixtures shows that they yielded significantly more than genotypically homogenous crop stands in the face of high disease pressure (Reiss and Drinkwater 2017). A second meta-analysis that examined the ecosystem services provided by plant diversity again showed a significant increase in pathogen regulation (Quijas et al. 2010). In a third review of over 200 studies, intercropping was shown to reduce fungal disease by 79%, bacterial disease by 100%, and viral disease by 72%, but nematode diseases by only 37% (Boudreau 2013). Microbial biodiversity, which is supported in healthy soils with high organic matter and fertility, is also correlated to general disease suppression through a variety of mechanisms (Larkin 2015). Compost amendments can be used to increase soil health and were found to suppress disease in 54% (Termorshuizen et al. 2006) and 55% of studies (Bonanomi et al. 2007), respectively. Plants themselves also contribute to disease suppression through induced resistance by biotic and abiotic stimuli, which can reduce disease between 20 and 85% (Walters et al. 2013).

Despite these general trends, different types of enemies may respond differently to landscape composition (Shackelford et al. 2013). Indeed, a more recent and exhaustive synthesis indicates pests and enemies show extreme heterogeneity in their landscape responses, making it difficult to predict impacts of future land-use change on pest suppression (Karp et al. in review). Natural habitat may fail to provide pest control even when there is sufficient natural habitat in the landscape to support natural enemy populations, if, for example, pest populations have no effective natural enemies in the region, natural habitat is a greater source of pests than natural enemies, crops provide more resources for natural enemies than does natural habitat, or local agricultural practices counteract enemy establishment and biocontrol (Tscharntke et al. 2016).

2) Regulation of pathogens that affect humans

Vector-borne diseases (VBD) occur where permissive environmental conditions allow vectors, pathogens, and reservoir hosts to converge (Reisen, 2010). Human exposure to these VBD transmission cycles are governed by a set of complex social and ecological processes that regulate the persistence of these interactions in time and space (Cohen et al., 2016; Gage et al., 2008; Kilpatrick & Randolph, 2006; Lambin et al., 2010; Reisen, 2010; Sutherst 2004). Ecological processes, including elements of the biotic and abiotic environment, support the regulation of VBD in human populations by 1) preventing the establishment of disease transmission cycles (i.e. reducing the risk of disease emergence or re-emergence) and 2) maintaining endemic VBD transmission cycles in a state of relative equilibrium (MEA 2005; Myers et al., 2013; Whitmee et al., 2015). While the exact relationships between particular sets of ecological processes and specific VBD systems in humans is idiosyncratic, regulating functions can be broadly categorized by how they relate to vectors, hosts, and the physical contact between pathogen-infected vectors and susceptible humans (LaDeau et al., 2015; Lambin et al., 2010; Pfäffle et al., 2013; Wilcox & Colwell 2005; Wimberly et al., 2008).

The global burden of VBD is driven, in large part, to Malaria in sub-Saharan Africa (Murray et al., 2012; WHO, 2014). However, in recent years numerous VBD have emerged in new geographic region or grown in regions where the pathogen has been endemic (Jones et al., 2008; Kilpatrick and Randolph, 2012; Weaver and Lecuit, 2015). Recently, several large-scale assessments have been conducted to map global trends and patterns of VBD, including workshops convened by the National

Academies of Sciences, Engineering, and Medicine (NASEM, 2016) and the Rockefeller Foundation's Lancet Commission on planetary health (Whitmee et al., 2015). The consensus suggests that social and ecological changes will alter the future landscape of VBD risk by 1) altering the epidemiology of endemic diseases, 2) facilitating the introduction of novel pathogens and vectors, and 3) increasing the likelihood that newly endemic pathogens will be discovered (NASEM, 2016).

The presence of vectors is necessary, but not sufficient for VBD. The natural transmission cycles of VBD are maintained when pathogens are able to survive and multiple in reservoir hosts. The composition of both reservoir and incidental (dead-end) hosts species in particular ecosystems play a significant role in the regulation of VBD. Host species richness (i.e. biodiversity) may increase (through pathogen amplification) or decrease (through pathogen dilution) the prevalence of pathogens in a particular system (Cohen et al., 2016). Evidence suggests that ecological processes associated with the maintenance of high levels of biodiversity can regulate VBD by altering vector-host biting rates and lowering pathogen prevalence (Keesing et al., 2006; Keesing et al., 2010; Laporta et al., 2013; Ostfeld & Keesing, 2000; Wood and Lafferty, 2013; Xavier et al., 2012). However, the complete regulating effects of these mechanisms are not fully understood and are likely highly depended on specific VBD transmission cycles (Salkeld et al. 2013; Titcomb et al. 2017).

Mosquitoes are among the most impactful vectors affecting human health; however, others such as fleas, ticks, flies, triatomine bugs, and some freshwater snails contribute to a substantial portion of the worldwide burden of disease (WHO, 2014). Across these different species lies a common sensitivity to particular sets of habitat features. Abiotic factors, such as temperature and precipitation, regulate VBD by placing constraints on vector distributions, densities, survival, reproduction, and the ability to acquire and transmit microbial pathogens (i.e. vector competence) (Diuk-Wasser et al., 2010; Gage et al., 2008; Ostfeld 2009; Pfäffle et al., 2013; Wimberly et al., 2008). Many of these constraining factors are further influenced by elements of the biotic environment, such as vegetation cover, in different ecological systems (i.e. forest, wetland, urban) (Harvell et al., 2002; Ostfeld et al., 2006; Wimberly et al., 2008). The result is a set of ecological processes that place specific limits on where and when vectors will occur.

Ecological processes that inhibit or maintain the transmission of pathogens between vectors and hosts define the background level of VBD risk in a location. The abundance of pathogen infected vectors is the most important indicator for disease risk (Reisein, 2010). However, risk only manifests as disease when sufficient contact is made between susceptible humans and the requisite VBD transmission cycle. The ecological processes that regulate this contact are those that prevent spillover events from zoonotic hosts or reduce contact between humans and the focal points of disease risk (Despommier et al., 2006; Lambin et al., 2010; Kurtenbach et al. 2006). Contact risk between humans and pathogen infected vectors may be highest at the interface of preferred vector-host habitats, such as the edge of forests, and human settlements (Allan et al., 2003; Despommier et al., 2006; Gottdenker et al. 2014). While ecological processes define environmental conditions for VBD risk, human entry into these high-risk zones are fundamentally influenced by human behavior and socioeconomic conditions (Bayles et al., 2013; Lambin et al., 2010; LaDeau et al., 2015.)

Summary bullet list of how this NCP is produced:

- ***Direct***: Regulation of agricultural pests is produced through predation and parasitism by natural enemies. Regulation of vector-borne diseases is produced through the "dilution effect", by which higher diversity reduces disease risk.
- ***Direct***: higher landscape complexity and habitat diversity increases natural enemies and alternative hosts for pests and pathogens.

10.3.2. How is (co)production of this NCP measured?

Crop damage decreases with increasing natural enemy abundance, diversity and activity. These three variables increase with increasing landscape complexity.

Disease prevalence increases with increasing abundance of pathogen infected vectors. This variable decreases with increasing species richness and abundance of alternative hosts.

10.3.3. Links to other NCPS

NCP2 – pollination -
NCP3 – air quality -
NCP4 – climate -
NCP5 – ocean acidification -
NCP6 – water quantity – Natural pest regulation reduces pesticide use and thus pollution of water and soils with pesticides
NCP7 – water quality -
NCP8 – soils -
NCP9 – hazards -
NCP10 – pests –
NCP11 – energy -
NCP12 – food – Food provision depends on pest regulation. Natural pest regulation reduces pesticide use and thus food contamination with pesticides
NCP13 – materials –
NCP14 – medicine -
NCP15 – learning –
NCP16 – experiences -
NCP17 - identities -

10.3.4. Indicators of NCP (co-) production

NCP	Production Function	Indicator/ Proxy	Rationale/ justification for why this indicator/ proxy was selected
Regulation, by ecosystems or organisms, of crop pests, and pathogens		Near- or on-farm habitat diversity	Near- or on-farm habitat diversity increases the abundance of natural enemies of pests such as predators and parasitoids
Regulation, by ecosystems or organisms, of crop pests, and pathogens		Landscape complexity	Landscape complexity is usually associated positively with near- or on-farm habitat diversity
Regulation, by ecosystems or organisms, of human pathogens		Abundance of alternative hosts species	Alternative hosts reduce the prevalence of vector-borne diseases
Regulation, by ecosystems or organisms, of human pathogens		Species richness	Species richness is positively associated with the abundance of alternative hosts of human pathogens

10.3.5. Trends in Co-Production

10.3.5.1. General (across all units of analysis)

1) Regulation of pests and pathogens that affect plant crops
The regulation of insect pests and diseases is unlikely to be uniform in all regions of the world. Temperature and precipitation are important factors regulating pests and pathogens and these climatic factors vary with latitude and biome. One study of the effect of latitude on biological control found that caterpillar predation increases towards the tropics with a 2.7% increase in the odds of pest attack with every one degree move towards the equator (Roslin et al. 2017). However, it is unclear whether shorter development times of insect pests in the tropics compared with temperate climates would counteract this increase in biological control. It has also been proposed that tropical agroecosystems are more dependent on biological control for pest regulation than temperate agroecosystems because they do not experience the frosts that reset pest levels every year in temperate climates (Matteson 2000). Soil carbon, which is an important factor in disease regulation, varies with biome as well as human activities. Soil degradation and carbon loss tends to be higher in developing countries than in developed countries, especially in Africa and Asia, and may contribute to reduced disease regulation in these regions (Bai et al. 2008). On the other hand, on-farm as well as landscape-scale diversity (due to many small farms) also tends to be higher in developing than developed countries and may contribute to better regulation of pest and diseases there (Fan and Chan-Kang 2005). Indeed, landscape complexity does appear to enhance natural pest control (Chaplin-Kramer et al. 2011), especially for aphids across North America and Europe, which show a 46% decline in the average level of pest control with landscape simplification (Rusch et al. 2016). When these factors are considered together, it becomes very unclear how regulation of pests and pathogens varies across the globe because many ecological factors such as temperature, precipitation, soil health, and biodiversity are all important and can have counteractive influences. Our insight into how ecological pest and pathogen regulation varies regionally is also hampered by the fact that the vast majority of related studies are conducted in temperate systems in developed countries (Chaplin-Kramer et al. 2011, Shackelford et al. 2013, Wyckhuys et al. 2013, Reiss and Drinkwater 2017).

In fact, local farming practices can be more important than landscape factors, and many farmers are actively managing their farms to increase natural pest suppression (Gurr et al. 2016). Increasing local plant diversity via polyculture, hedgerows, flower strips, or intercropping requires little to no loss in production area, and several syntheses suggest that these approaches enhance natural pest control. In-field plant diversification increases local richness of arthropods, more strongly for enemies than for pests (Lichtenberg et al. 2017). Polycultures boost biocontrol (measured as reductions in pest abundance and plant damage) by 31-36% relative to monocultures (Iverson et al. 2014). Finally, high-diversity cropping systems (including intercrops, nonspecific plants within the fields, trap crops, and floral margins) increase average abundance of natural enemies by 44% and average herbivore mortality by 54% relative to low-diversity cropping systems (Letourneau et al. 2011).

While local and landscape diversity may help maintain and enhance pest control year to year, longer-term studies are needed to better understand the cumulative effects over time and to document temporal trends in pest control. Decadal or longer datasets are rare in this field, but two examples point to the importance of considering relationships between pests and enemies over longer time frames. First, as chemical pesticides were gradually replaced with organic production from the 1980s to 2000s in Sweden, ground beetle communities shifted to favor larger, more effective, generalist predators (Rusch et al. 2013). Second, a multi-decadal study in New Zealand attributed sudden declines in the effectiveness of a biocontrol agent seven years after its introduction to the rise of intensive, large-scale agriculture and decline in plant and enemy diversity (Tomasetto et al. 2017).

Stability in herbivore populations and in the efficiency of regulation services have been attributed to the complexity of interactions between component species (biodiversity)(Ings et al., 2009). The diversity of natural enemies is normally higher in tropical and subtropical regions compared to temperate regions suggesting that regulation services may be more stable for tropical crops such as sorghum, millet, sugarcane, peanuts and cassava (Gaston 2000; Leff et al., 2004). In forests for example, low diversity northern forests are prone to often-periodic herbivore outbreaks, whereas tropical forests seldom experience largescale defoliation and foliage tends to be better protected from herbivores by natural enemies (Coley and Barone 1996). For crops, such as rice, that are produced in temperate, subtropical and tropical regions, the diversity of herbivore pests and their natural enemies is highest in the tropics; however, efficient pest regulation prevents severe pest damage to rice in the tropics, whereas outbreaks are apparently more frequent at higher latitudes (Horgan and Crisol 2013; Hu et al., 2014). Key pests such as planthoppers and leaffolders that migrate from tropical to temperate regions during the high-latitude springtime can cause severe outbreaks in Asia when natural enemies become overwhelmed by large numbers of migratory pests; however parasitoids that develop on non-pest hosts in field verges can reduce the severity of outbreaks in these regions (Yu et al., 2001). Therefore, the avoidance of monocultures in higher latitudes or the establishment of set-aside natural areas might be more important than in tropical regions to promote neighborhood effects (amplification of landscape effects where critical resources for natural enemies immediately surround patches of natural habitat)(Dunning et al., 1992); alternatively, adequate management of winter fallows that promotes the survival of natural enemies might reduce crop vulnerability to springtime migrants and other early season pests.

Large areas of open agricultural lands dedicated to commodity production are prominent in North America (USA and Canada), China, Russia and Australia in areas that were once prairies and steppes – agricultural intensification in these regions has relied on relatively high inputs of fertilizers, pesticides, and energy compared to tropical regions (Leff et al., 2004). Small scale agriculture in tropical regions is often dominated by subsistence agriculture that tends to be more diverse, maintains traditional practices, and has a greater degree of adjacent natural areas and unmanaged vegetation where natural enemies find food and refuge during periods of low herbivore availability (Knudsen et al., 2006; Leff et al., 2004). Recolonization of tropical crop lands following perturbations is therefore expected to be more efficient than for temperate lands. In many cases, temperate agriculture will need to restore efficiency to ecological processes if it is to increase environmental sustainability and reduce dependency on high inputs. Successful experiences in the regulation of pests in organic and low-input agriculture in temperate regions suggest that such a balance is achievable (Kajimura et al., 1993; Crowder et al., 2010).

2) Regulation of pathogens that affect humans

Anthropogenic pressures are quickly altering the ecological processes that regulate vector-pathogen-host dynamics and are creating new opportunities for transmission and spread into susceptible human populations (Altizer et al., 2013; Dirzo et al., 2014; Foley et al., 2005; Myers et al., 2013). The highest risk areas are likely to be where human and wildlife populations overlap, and where ecological disruptions facilitate sustained VBD transmission cycles (Jones et al., 2008). These VBD hotspots are projected to be the result of climate change, loss of biosphere integrity (i.e. biodiversity), and land-use change (including agriculture intensification, urbanization, and deforestation) (Keesing et al. 2006; Keesing et al. 2010; Kilpatrick & Randolph, 2012; Laporta et al. 2013; Ostfeld et al. 2006; Xavier et al. 2012)

The impact of environmental change remains largely unclear and will likely be dependent on ecological and socio-economic factors within a regional context. Evidence of environmental change suggests an increased risk of VBD transmission in Latin America, Africa, and Asia (Benedict et al., 2007; Castellanos 2016; Guerra et al., 2006; Jones et al., 2008; Kilpatrick and Randolph 2012; Messina et al., 2016; Murray et al., 2013; Sokolow et al., 2017; Vorou et al., 2007; Weaver & Lecuit, 2015). This trend will likely extend world-wide, with examples of rapid VBD disease emergence and re-emergence in North America, Europe, and Oceania (Dujardin et al., 2008; Kugeler et al., 2015; Murray et al., 2013; Peterson et al., 2013; Peterson et al., 2016; Sutherst 2004). However, these trends in increased risk will likely manifest as different rates of morbidity and mortality according to the social response in certain regions (adoption of integrated vector management, vaccination coverage, etc.).

10.4. Impacts on good quality of life

10.4.1. Different types of value

10.4.1.1. What is the NCP contribution

The ecological regulation of crop pests and pathogens contributes to good quality of life in many ways. It protects crop yields, offsets pesticide use, and slows rates of pesticide resistance. For example, Losey and Vaughan (2006) estimated that biological control of insect pests accounts for over $13 billion in protected yield in the U.S. alone. Naranjo et al. (2015) summarized studies that calculated the avoided cost of insecticide use due to biological control of insect pests, and found values ranging up to thousands of dollars per hectare for some high value horticultural crops such as cabbage and oranges. This represents just the avoided direct costs of pesticides and not the avoided indirect costs. These indirect costs include environmental degradation, costly pesticide regulatory systems, and human health impacts, which can sometimes be more than the value of the yields preserved by pesticide use (Bourguet and Guillemaud 2016). Modeling and empirical studies also show that biological control helps to delay the resistance evolution of pests to pesticides (Gassmann et al. 2006, Liu et al. 2014). Delaying resistance evolution is important because it has been estimated that approximately 10% of pesticide use is directed solely at resistant pests (Pimentel 2005).

The benefits of ecological pest management are not homogenous throughout the world. They will depend on a variety of factors including a person's occupation. Farmers directly experience health benefits from ecological regulation of pests and pathogens due to avoided pesticide use. Numerous studies have documented the acute and chronic toxicity impacts of pesticides on farmers and even the children of female farm workers exposed to pesticides during pregnancy (Calvert et al. 2007, Bouchard et al. 2011, Muñoz-Quezada et al. 2017). These health impacts of pesticides may fall disproportionately on farmers in developing countries where pesticides are often not strictly regulated, proper disposal facilities are non-existent, labels may be written in foreign languages, and many farmers are illiterate (Ecobichon 2001). Indeed, 71% of low income countries do not restrict pesticides considered hazardous by the Rotterdam Convention (Schreinemachers and Tipraqsa 2012).

How much a country depends on conventional pesticides for food production will also help determine how ecological pest and pathogen regulation affect quality of life there. In general, low income, developing countries are much more dependent on ecological pest regulation than developed countries. In a study of worldwide pesticide use, low income developing countries (the majority of which are in Sub-Saharan Africa) tended to use less than .1 kg a.i. of pesticides per hectare compared with 2.4 kg a.i. per hectare in high income countries (Schreinemachers and Tipraqsa 2012). East Africa is also the only region in the world that actively manages an insect pest by ecological engineering to harness plant defensive chemistry and natural enemies. Thousands of subsistence farmers in East Africa employ the “push-pull” strategy to control stem borer pest insects in corn and sorghum. In this strategy, non-host plants are intercropped with corn and sorghum. This intercropping diversity promotes parasitism of the pest, while the non-host plant repels it out of the field and a trap plant attracts it using volatile chemicals and also interferes with its reproduction by producing a gummy substance (Cook et al. 2007).

Income is another important factor determining who benefits from ecological pest and pathogen regulation. Consumers who preferentially buy foods produced without pesticides or following organic guidelines are major beneficiaries of ecological pest regulation. In order for consumers to assuredly buy foods produced with organic or no pesticides, there must be a reliable regulatory framework in place. This is typically an organic label that complies with International Federation of Organic Agriculture Movements (IFOAM) standards. Many developing countries do not have reliable regulatory frameworks, and, accordingly, have only negligible amounts of organic food available for purchase (Willer and Lernoud 2016). Consumers must also be able to afford the price premium of organic that can vary from 10-40% above conventionally produced food in the U.S. to 500% higher in China (Thøgersen et al. 2015). This means that consumers who are wealthy and live in developed countries disproportionately benefit from the ecological regulation of pests and pathogens because they have access and can afford to buy organic foods. Ironically, since pesticide use tends to be more poorly regulated in developing countries than in developed countries (Ecobichon 2001), the health benefits to consumers from buying organic food and avoiding pesticide residues might actually be higher in developing than in developed countries (Liu et al. 2016).

Among the 18 most important agricultural crops, 15 are mainly commodity crops used extensively in industry or processed to a high degree after harvest (Leff et al., 2004). Economic injury levels (densities at which pests cause yield losses) for these crops are often high because agriculture can tolerate considerable damage to leaves and shoots, and because many of the crops have significant herbivory tolerance (i.e., able to compensate for damage without associated yield reductions), particularly grasses such as wheat, maize, rice, barley, sorghum, millet and sugarcane (Higley and Pedigo 1993; Horgan and Crisol 2013; Ney et al., 2013). In contrast, fruits and vegetables have lower economic injury levels because damage is seldom acceptable to consumers (Kogan 1998; Peterson and Hunt 2003). Regulation of direct pest damage to fruit and vegetable crops with acceptable losses may depend on some of the crop being used for commodity and value-added markets (for example, deformed and damaged apples are often used for beverages or jams). A suite of natural enemies regulate herbivore pests, including herbivore vectors of plant diseases, at densities below economic injury levels; however, in many cases, adequate habitat and landscape conditions must be provided to ensure efficienct pest regulation (Bianchi et al., 2006; Gurr et al., 2016). The provisioning of habitat has been shown to enhance the regulatory services of predators such as insectivorous birds and bats (Boyles et al., 2011; Horgan et al., 2017), predatory ants, beetles and spiders (Schmidt et al., 2005; Bianchi et al., 2006), parasitoids such as ichneumonid and mymarid wasps (Olson and Wäckers 2007; Gurr et al., 2016), and early-season granivores such as birds (cereals developing after grain-fall are often the principal weeds for successive crops)(Stafford et al., 2010).

Greater prioritization of long-term studies is also needed to better understand the role of natural enemies in preventing pest outbreaks. Farmers often make pest-management decisions based on minimizing risk rather than maximizing profits (Mumford and Norton 1984), and their actions will likely reflect their perceived risk of an outbreak. While enemies have been shown to respond rapidly to field experiments of simulated outbreaks (Perfecto et al. 2004), documenting impacts on the infrequent outbreaks that naturally occur requires long-term, spatially-distributed studies.

Fortunately, some adequate datasets already exist, others are being compiled, and new ecoinformatic approaches are being developed to analyze them (Rosenheim and Gratton 2017). Long-term spatial informatics will be a key research frontier to secure more reliable pest control services and more sustainable pest management for agriculture.

The International Organisation for Biological Control (IOBC) supports efforts to regulate crop pests and pathogens by ecological processes by a range of strategies. In conservation biological control, vegetation patterns and farming practices are altered specifically to promote the impact of predators, parasitoids, pathogens etc that are already established in a region. An important examples include 'push-pull' systems in East African cereal crops in which the volatile emitting non-crop plants are grown in cereal crop fields. These volatiles are perceived by pests as signals of heavily attacked host plants so 'push' pests from the crop, yet predators and parasitoids are 'pulled' to the crop in search of prey/hosts (Khan or Pickett refs). In East Asia, rice fields have been the focus of conservation biological control using nectar-producing plants grown in field margins. These provide nectar to parasitoids, leading them to parasitise planthopper pests more heavily. This effect has reduced pest densities to the extent that farmers reduce insecticide spray frequency by two-thirds and gain rice yield benefits of 5% resulting in an overall economic advantage of 7.5% (Gurr et al. Nature Plants). In temperate areas of North America and Western Europe, overwintering survival of predators and parasitoids is enhanced by 'beetle banks'; perennial grass-covered ridges that dissect fields and provide areas of moderated microclimate from which spiders and predatory beetles rapidly disperse into the adjacent crop in the spring (Thomas or Wratten ref).

An alternative form of biological control involves the inoculative release of exotic agents not new geographical regions (ref). This approach has been used since the 1880 and though its success rate has hovered around 10%, it can provide effective, cheap and self-sustaining control of target pests when effective.

The third major form of biological control involves the mass release of predators, parasitoids or pathogens with little or no local persistence; effectively a form of 'biological insecticide'.

10.4.1.2. How do we measure that value/contribution?

Economic value of avoided costs
Health benefits in terms of reduced disease prevalence

10.4.1.3. Substitutability

For natural pest regulation

1. Genetically modified organisms and pesticides
2. Pesticides only

For natural regulation of human diseases

1. Vaccination
2. Insecticides, bed-nets, etc

10.4.2. Indicators of NCP impact

10.4.2.1. Indicators by value

Value type	Indicator/ Proxy
Economic	Avoided costs of pesticide use
Economic	Avoided costs of health treatment of VBD

Health	Reduced pesticide use
Health	Reduced prevalence of VBD

10.5. Summary

While ecological pest and pathogen regulation certainly contribute to good quality of life across the world currently, it is difficult to assess who accrues the most benefits just like it is difficult to assess regional differences in ecological pest and pathogen regulation. There are so many factors at play coupled with an academic bias towards research in developed, temperate countries. What we do know is that pesticides disrupt ecological pest and pathogen regulation and that potential benefits are much greater than what we currently realize. According to Pimentel (2005), pesticide use could be reduced by up to 50% without any loss of yield or crop quality by employing good agricultural practices that include increasing cropping system diversity and improving plant health. Indeed, despite an approximate 20-fold increase in insecticide and fungicide sales worldwide between 1964 and 2004, the percentage of wheat, maize, and cotton lost to insects and disease rose slightly (Oerke 2006).

	Potential Nature's Contributions	**Output of the joint production**	**Impact on good quality of life**
Indicator	a) Diversity of biological controllers of pests b) Diversity of competent hosts of vector-borne and zoonotic diseases	a) Abundance of wild and managed biological controllers of pests b) Abundance of competent hosts of vector-born and zoonotic diseases	a) Avoided pest damage to crop and livestock b) Reduced pesticide use c) Reduced incidence rate of vector-borne and zoonotic diseases
Trend During the last 50 years: 2 = Major increase (>20%) 1 = Increase (5% to 20%) 0 = No change (-5% to 5%) -1 = Decrease (-20% to -5%) -2 = Major decrease (< -20%)	a) -2 b) -2 There´s a general decline of natural pest enemies and mammalian species that act as competent hosts of vector-borne and zoonotic diseases	a) -1 b) -2 There´s a general decline of natural pest enemies, although there is increased use of managed pest enemies. Mammalian species that act as competent hosts of vector-borne and zoonotic diseases have experienced significant declines.	a) -1 b) -1 c) -1 The increasing simplification of agricultural system in the last 50 years has been associated with declines in natural pest control, increased pest emergence and increased pesticide use. Avoided costs from natural pest control (reduced crop and livestock damage and reduced pesticide use) may have declined. Vector-borne disease incidence has decreased from 1950 to 1980 but has increased in the last 30 years. The incidence

			and frequency of epidemic transmission of zoonotic diseases, both known and newly recognized, has increased dramatically in the past 30 years.
Spatial variance 3 = opposite trends in different regions 2 = same directional trends in different regions but of contrasting magnitude 1 = similar trends all over the world	a) 2 b) 2 Natural pest enemies and competent hosts of human diseases are declining in all regions, with larger declines in tropical and sub-tropical areas.	a) 2 b) 2 Natural and managed pest enemies and competent hosts of human diseases are declining in all regions, with larger declines in tropical and sub-tropical areas.	a) 2 b) 2 c) 2 The impacts of increased pest damage and pesticide use negatively affect all regions, with South America and South East Asia experiencing the highest negative impacts (cita). The impacts of increased vector-borne and zoonotic disease incidence negatively affect all regions, with sub-Saharan Africa, South America and South-East Asia experiencing the largest global burden of vector-borne and zoonotic diseases (WHO, 2014)
Variance across user groups 3 = opposite trends for different groups 2 = same directional trends for different groups but contrasting magnitudes 1 = similar trends for all social groups	NA	NA	a) 3 b) 3 c) 3 The negative impacts of increased pest damage and pesticide use are disproportionally borne by subsistence and commercial harvesters, who depend on crop and livestock yields. The negative impacts of increased incidence of vector-borne and zoonotic diseases are disproportionally borne

			by the rural poor in developing countries, who is in closer contact with disease vectors and have less access to prevention and health services.
Degree of certainty 4 = **Well established**: 3 = **Established but incomplete**: t 2 = **Unresolved**: 1 = **Inconclusive**:	a) 4 b) 4 Diversity declines in natural pest enemies and mammalian species are well documented	a) 3 b) 3 Declines in abundance of managed and natural pest enemies and mammalian species are agreed upon, but not as well-documented as diversity declines	a) 3 b) 3 c) 3 There is general agreement that these three outputs have increased over the last 50 years, although there is little empirical data supporting the trend
Two to five most important papers supporting the reported trend	Wyckhuys, K. A., Y. Lu, H. Morales, L. L. Vazquez, J. C. Legaspi, P. A. Eliopoulos, and L. M. Hernandez. 2013. Current status and potential of conservation biological control for agriculture in the developing world. Biological Control 65:152-167. Myers, S. S., Gaffikin, L., Golden, C. D., Ostfeld, R. S., Redford, K. H., Ricketts, T. H., ... & Osofsky, S. A. (2013). Human health impacts of ecosystem alteration. Proceedings of the National Academy of Sciences, 110(47), 18753-18760. Keesing, F., Belden, L. K., Daszak, P., Dobson, A., Harvell, C. D., Holt, R. D., ... & Myers, S. S. (2010). Impacts of biodiversity on the emergence and transmission of infectious diseases. Nature, 468(7324), 647.	Wyckhuys, K. A., Y. Lu, H. Morales, L. L. Vazquez, J. C. Legaspi, P. A. Eliopoulos, and L. M. Hernandez. 2013. Current status and potential of conservation biological control for agriculture in the developing world. Biological Control 65:152-167. Myers, S. S., Gaffikin, L., Golden, C. D., Ostfeld, R. S., Redford, K. H., Ricketts, T. H., ... & Osofsky, S. A. (2013). Human health impacts of ecosystem alteration. Proceedings of the National Academy of Sciences, 110(47), 18753-18760. Keesing, F., Belden, L. K., Daszak, P., Dobson, A., Harvell, C. D., Holt, R. D., ... & Myers, S. S. (2010). Impacts of biodiversity on the emergence and transmission of infectious diseases. Nature, 468(7324), 647.	FAO (2017) The future of food and agriculture: Trends and challenge. World Health Organization. (2014). A global brief on vector-borne diseases. Wilcox, B. A., & Gubler, D. J. (2005). Disease ecology and the global emergence of zoonotic pathogens. Environmental Health and Preventive Medicine, 10(5), 263-272.

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11. NCP 11: Energy

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11.1. IPBES Definition:

Production of biomass-based fuels, such as biofuel crops, animal waste, fuelwood, agricultural residue pellets.

11.2. Why is this NCP important?

Energy access is the “golden thread” that weaves together economic growth, human development and environmental sustainability (IEA, World Energy Outlook 2017).
Energy has long been recognized as essential for humanity to develop and thrive, but the adoption in 2015 by 193 countries of a goal to ensure access to affordable, reliable, sustainable and modern energy for all by 2030, as part of the new United Nations Sustainable Development Goals (SDGs), marked a new level of political recognition. Energy is also at the heart of many of the other SDGs, including those related to gender equality, poverty reduction, improvements in health and climate change (IEA, World Energy Outlook 2017).

Energy security has traditionally been the major driver behind biofuel expansion, while rural development, climate change mitigation and other economic factors (e.g. economic growth, foreign exchange savings) have been additional important motivations in some national and regional contexts. Dependence on non-renewable fossil fuels as well as environmental concerns related to air pollution and greenhouse gas effects contributing to global warming and climate change have stimulated interests of policy makers and industry to promote bioenergy as part of energy security and climate change mitigation strategies. But there are renewable fuels which are derived from biological sources or feed-stocks. They include both liquid and gaseous forms like bioethanol (gasoline equivalent) or biodiesel or biogas (e.g. methane) or hydrogen . Further rising fuel prices coupled with concerns about carbon emissions are making biofuel production more cost competitive and attractive (Koh et al., 2008)

This NCP is particularly important for the energy security scenario. With increasing development and raising standards of living energy demands are going to rise continuously in future. To meet these demands and reduce reliance on fossil fuels, biofuels have significant role to play. Biofuels not only give alternative fuel options but are also environmentally friendly. By lowering the GHG emission and linkages to rural livelihoods, the three pillars of sustainability can be achieved.

Questions have been raised to assess the net emission scenario of biofuels and its impact on food security and food prices in the changing land-use scenario. But keeping in view the importance of this NCP (sub-group-biofuels) a proper life-cycle analysis (LCA) of the biofuels incorporating various by-factors and assessment of trade-offs will be key to determine its future course.

11.2.1. What is the big environmental issue this pertains to?

The International Energy Outlook projects strong growth for worldwide energy demand up to 2025. Total world consumption of marketed energy is expected to expand by 57% over the 2002–2025 time period. In the IEO2005 mid-term outlook, the emerging economies account for nearly two-thirds of the increase in world energy use, surpassing energy use in the mature market economies for the first time in 2020. In 2025, energy demand in the emerging economies is expected to exceed that of the mature market economies by 9%. Much of the growth in energy demand among the emerging economies is expected to occur in emerging Asia, which includes China and India; demand in this region is projected to more than double over the forecast period. Primary energy consumption in the emerging economies as a whole is projected to grow at an average annual rate of 3.2% up to 2025. In contrast, in the mature market economies—where energy consumption patterns are well established—energy use is expected to grow at a much slower average rate of 1.1% per year over the same period. In the transitional economies of Eastern Europe and the former Soviet Union, growth in energy demand is projected to average 1.6% per year (Asif & Muneer, 2007).

Dependence on non-renewable fossil fuels as well as environmental concerns related to air pollution and greenhouse gas effects contributing to global warming and climate change have stimulated interests of policy makers and industry to promote bioenergy as part of energy security and climate change mitigation strategies.

Biofuels have gained increasing attention as an alternative to fossil fuels for several reasons, one of which is their potential to reduce the greenhouse gas (GHG) emissions from the transportation sector. Recent studies have questioned the validity of claims about the potential of biofuels to reduce GHG emissions relative to the liquid fossil fuels they are replacing when emissions owing to direct (DLUC) and indirect land use changes (ILUC) that accompany biofuels are included in the life cycle GHG intensity of biofuels (Khanna et al., 2011).

Between 2003 and 2010, the average total energy annually released by fires equaled 14% of the total energy consumed by humans in 2008. In principle, if all of the biomass that fed these fires could be diverted to energy generation assuming an efficiency ranging from 33% to 40% conversion (efficiencies from the standard Steam-Rankine cycle and conservative commercially mature power generation facilities, respectively, Ganget al., 2009; Schiermeier et al., 2008), the burned biomass would supply between 36% and 44% of the global electricity consumption in 2008 (Energy Information Administration, 2008).

Thomas et.al. (2013) highlights that biomass needs a great deal of space per unit of energy produced but it is an energy carrier that may be strategically useful in circumstances where other renewable energy carriers are likely to deliver less. He argues that biomass energy also has a larger spatial footprint than other carriers such as, for example, solar energy and suggests for creating future 'energy landscapes' which can be modelled in time and space. He argues that these Landscapes, provide a concept of 'place' both urban and rural, linked to the community, an ability to transform perceptions of the world across physical and psychological boundaries, a framework for people's lifestyles and an interface (through concepts such as biodiversity) between people and nature. These landscapes are much larger than energy regions as depicted in the diagram below :

Global demand for energy is increasing rapidly, because of population and economic growth, especially in emerging market economies. As per WEO, 2017 four large-scale shifts in the global energy system set the scene for the World Energy Outlook 2017: the rapid deployment and falling costs of clean energy technologies, the growing electrification of energy, the shift to a more services-oriented economy and a cleaner energy mix in China, and the resilience of shale gas and tight oil in the United States.The Report further finds that the shifts come at a time when traditional distinctions between energy producers and consumers are being blurred and a new group of major developing countries, led by India, moves towards centre stage.

According to the UN, 220m people gained electricity between 2010 and 2012. But most of them were in urban areas, particularly in India. In sub-Saharan Africa, a region that, excluding South Africa, uses less electricity than New York state, electrification barely kept pace with population growth. Some 600m of its people are without electricity; demography means that by 2030 the number could be even higher (Economist, Feb, 2016). The scenario is well depicted in the following diagram.

In the New Policies Scenario, demand for cooking fuel increases across sub-Saharan Africa in the period to 2030, as the population continues to grow by 2.5% per year and GDP per capita by 1.9% per year. The fuel mix remains relatively constant. Bioenergy continues to provide around 90% of residential energy needs up to 2030, and demand grows by more than 1% per year. The number of people relying on the traditional use of biomass for cooking continues to increase until the early 2020s, as efforts to provide access are outmatched by population growth, but after that it starts to decline as policies start to deliver.

Why is Biomass Energy (BME) important?

Biomass energy is considered a renewable form of energy because the organic materials used to produce it are never-ending. The organic materials including wood, crop waste, garbage, sewage sludge, and manure are continually produced by society. In a nutshell, regrowth of these organic materials supports the fact that biomass is renewable. It can help mitigate climate change; reduce acid rain; prevent soil erosion and water pollution; minimize pressure on landfills; provide wildlife habitat; and help maintain forest health through better management.

We all know that release of vast amounts of carbon contributes greatly to climate change. Biomass energy takes care of this since it is a natural part of the carbon cycle as opposed to fossil-based sources of fuel such as oil, natural gas, and coal. The use of biomass will reduce the nation's greenhouse gas emissions.

Researchers say that the only carbon emitted to the environment from biomass fuels is the amount that was absorbed by plants in the course of their life cycle. In the process of replenishing the used plant materials, the new ones that spring up absorb equal quantity of carbon, hence, developing neutrality that witnesses no new carbon generated. This aspect renders biomass uniquely clean.

Biomass energy has rapidly become a vital part of the global renewable energy mix and account for an ever-growing share of electric capacity added worldwide. As per a recent UNEP report, total renewable power capacity worldwide exceeded 1,470 GW in 2012, up 8.5% from 2011. Renewable energy supplies around one-fifth of the final energy consumption worldwide, counting traditional biomass, large hydropower, and “new” renewables (small hydro, modern biomass, wind, solar, geothermal, and biofuels). Traditional biomass, primarily for cooking and heating, represents about 13 percent and is growing slowly or even declining in some regions as biomass is used more resourcefully or replaced by more modern energy forms. Some of the recent estimates suggest that biomass energy is likely to make up one third of the total world energy mix by 2050. Infact, biofuel provides around 3% of the world’s fuel for transport. Bioenergy systems offer substantial possibilities for reducing greenhouse gas emissions due to their immense potential to replace fossil fuels in energy production.

11.2.2. How does this NCP play a role?

Being the predominant energy source in preindustrial times, land ecosystems are gaining renewed attention as energy providers. Biofuels can provide answers to current global energy and economic crises - both as a sustainable energy source and through promoting economic development, especially in rural areas of developing countries. The main drivers behind the growth of biofuels are (i) energy supply security (ii) Support for livelihoods for rural community and agricultural industries, (iii) Reduction in dependence on fossil fuels and oil imports, and potential reduction in GHG emissions (Sims et. Al., 2010).

With the rising energy demands, alternative fuels are have become need of the hour. In this field, biofuels are effective options with significant future potential. They can not only cater to the energy security goal but are also carbon effective in doing so. This NCP can have several identified benefits like providing source of income, creating employment opportunities and contributing to the economy3. Biofuels can also be seen as a social intervention and have impact on livelihoods and social dynamics as explained in further sections1.

As per Dale *et al*., 2017, the biofuels affect the ecosystem services on local and regional levels it affects provisioning services like food, feed, water and fiber, cultural services like aesthetic value and recreation, and regulating and supporting services like (i) water provisioning and quality regulation, (ii) regulation of toxins, waste and other nuisances, and (iii) maintenance of biological and chemical balance in the system. There are also trade-offs and it is important to highlight them in order to make better policy decisions.

Biomass is the only renewable energy source that can be converted into liquid biofuels such as ethanol and biodiesel. Biofuel is used to power vehicles, and is being produced by gasification in countries such as Sweden, Austria, and the United States. Ethanol is made by fermenting biomass that is high in carbohydrates, such as sugar cane, wheat, or corn. Biodiesel is made from combining ethanol with animal fat, recycled cooking fat, or vegetable oil. Biofuels do not operate as efficiently as gasoline. However, they can be blended with gasoline to efficiently power vehicles and machinery, and do not release the emissions associated with fossil fuels. Ethanol requires acres of farmland to grow biocrops (usually corn). About 1,515 liters (400 gallons) of ethanol is produced by an acre of corn. But this acreage is then unavailable for growing crops for food or other uses. Growing enough corn for ethanol also creates a strain on the environment because of the lack of variation in planting, and the high use of pesticides. Ethanol has become a popular substitute for wood in residential fireplaces. When it is burned, it gives off heat in the form of flames, and water vapor instead of smoke (nationalgeographic.com).

Schiermeier *et al.* (2008) identifies three key qualities that will be required in future energy systems: _ low energy usage, as a result of switching to high-efficiency application and transformation technologies, _ low carbon emissions, achieved by the phasing out fossil fuels and increased use of renewable energy, and _ low transport distances, achieved by realizing the potential of locally available energy sources including solar, wind, hydro and biomass applications. Many countries like US, Brazil, Indonesia and others have already started moving towards these alternative fuels. With increasing global outreach, it is important to study in detail about this NCP.

11.3. (Co-) production

11.3.1. How is it produced?

Bioenergy is renewable energy made from materials derived from biological sources. Biomass feedstock include any organic material that has stored energy from sunlight in the form of chemical energy, such as plants, residues from agriculture or forestry, and the organic component of municipal and industrial wastes (Dale *et.al* 2016). World's Top Biofuel Crops comprise of switch grass, wheat, sunflower, cottonseed oil, soy, jatropha, palm oil, sugar cane, canola, corn (nationalgeographic.org). Although forestry and agricultural areas provide the majority of biomass energy resources, both at present and most probably in the future, there are significant potential land resources for biomass cultivation that may have less impact on biodiversity, including street plantations and roadside verges, urban greens, recreation areas, waste dumps and contaminated sites (Thomas *et.al* 2013).

Timber, crop residues, and other biological energy sources are important for more than two billion people (Schiermeier *et.al*, 2008). These fuels are mostly burned in fires and cooking stoves, but in recent years biomass has also become a source of fossil-fuel-free electricity. Bioenergy promises to bring a shift in the geopolitics of energy. Many regions with a high production potential want to become oil and gas independent, and green fuel exporters

Pogson *et.al* (2013) finds through Computer simulation models that since land-based bioenergy is restricted by the need to grow food for an expanding population,
and technological developments are likely to greatly increase the viability of other renewable sources, the role of land-based bioenergy appears relatively limited and short-term. He further states that with advances in conversion efficiency, lifespan, production methods and reduced land rental all able to vastly increase the viability of solar power. This would further decrease the role of bioenergy at a global scale.

Summary

Biofuels are produced from various sources and can be categorized based on the raw material used. First generation biofuels are produced from food crops like fruits, sugarcane while biofuels prepared from lingo-cellulosic feedstock material like byproducts (cereal straw, sugarcane bagasse, forest residues), wastes (organic compounds of municipal solid wastes) and dedicated feedstock (purpose grown vegetative grasses, short rotation forests and other energy crops) are known as second generation biofuels4. The third generation is a growing category with the prospects of synthesizing biofuel from algal or microalgae biomass (Choudri *et al. ,* 2017). The authors further finds that biofuel is extracted from these sources by various bio-chemical or thermo-chemical processes like fermentation, hydrolysis, transesterification and valorization using bio chemical catalysts .

Bioethanol is the most commonly produced biofuel in the world (Fulton *et al*., 2004). It is produced from fermentation of corn (Zea mays), sugarcane (Saccharum spp.) or other starch- or sugar-rich crops. It can also be produced from cellulosic matter like grasses (e.g. switchgrass, Panicum vigratum), trees (e.g. willow, Salix spp.), agricultural residues, or municipal solid waste via complex pathways (Koh *et.al*. 2018).

Research and development trends of NCP production

There has been substantial increase in research and development related to biofuels as a promising alternative fuel option. Research topics include whole range of supply chain related to biofuels i.e. from production, extraction and usage (blends).

Greater emphasis is being made on conversion of biofuels from second and third generation sources so that the burden on food crops can be reduced (Choudri *et.al* 2017). Where these biomasses are easily available with no additional land requirement (Sims *et.al* 2010). The residues and wastes have technically a potential supply of over 100EJ/year of energy at the cost of USD 2-3/GJ (IEA Bioenergy, 2007). The second generation It will also result in effective utilization of residues from various agricultural and industrial processes. For instance, waste generated from cotton industry in Australia, if utilized as biofuel through pyrolysis of cotton stalks it has a potential to generate $104 million dollars. Which is otherwise wasted as 24.8 Pj of energy equivalent of coal worth $94 million dollars (Hamawand et al., 2016). Other investigated sources for bioethanol are glycerol, cane sugar/molasses, corn starch, cassava starch, cellulosic residues like wastes from juice industry (carrot) and beer brewing process (BSG), forest residues like wastes from softwood logging industry and eucalyptus bark along with various extraction technologies (Choudri *et.al*, 2017)

According to Barcelos *et al*. (2016), sweet sorghum is a very promising alternative raw material for ethanol synthesis. Its wide adaptability, high biomass productivity and short growth period make it an ideal source. Specifically, for Brazil, where it is already grown in abundance and will contribute to sustainable and renewable bioethanol production and addition to crop diversity without any major adjustments (Choudri *et.al* 2017).

Recent developments in microalgae research and advances in technologies have opened the jar of possibilities for use of microalgae as a source of alternative energy. Because of its properties like rapid growth rates, high biomass accumulation, and great oil productivity, in combination with CO2 capture and recycling capacities, make microalgae one of the most promising source for biofuel production with significant potential to beat the traditional sources such as agricultural crops. Extensive research is going on to make it an economically viable option for biofuel extraction (Choudri *et.al* 2017).

Alternative sources for biodiesel like second generation feedstock, vegetable oil, animal fat; for biomethane- wastes/residues from horticultural crops, glycerol; for biohydrogen- stillage and distillery waste water or effluents, glycerol; and for biobutanol- palm kernel cake, sugarcane are also among widely researched topics in 2015 (Choudri *et.al* 2017).

Moreira *et al.* (2016), studies bioenergy with carbon capture and storage (BESCC) techniques to further improve carbon footprint. Apart from this, Microbial fuel cell (MFC) technology option is being explored for bioelectricity production from orange peel waste; combination of dark fermentation (DF), anaerobic digestion (AD) and MFC integrated to co-produce valuable biochemical (Schievano *et al*. 2016).

Summary

- **Direct:** From first generation sources- food crops like sugarcane, fruits, palm oil; some second generation sources-lingo-cellulosic materials grasses like dedicated feedstock (purpose grown vegetative grasses, short rotation forestry and other energy crops), byproducts (cereal straw, sugarcane bagasse, forest /horticulture residues); and third generation feedstock like microalgae
- **Indirect:** From organic compounds of municipal solid wastes and industrial effluents

Although forestry and agricultural areas provide the majority of biomass energy resources, both at present and most probably in the future, there are significant potential land resources for biomass cultivation that may have less impact on biodiversity, including street plantations and roadside verges, urban greens, recreation areas, waste dumps and contaminated sites.

11.3.2. How is it measured?

Energy content of biomass

The energy from biofuels can be measured through five energy indicators viz. fossil or primary energy, secondary energy, cumulative energy demand, net energy balance and total extracted energy. Energy usage or energy content is usually measured in Joules (J) or similar units like (GJ, MJ or PJ) and /or with energy content in percentages (Choudri *et.al* 2017). It is also measured in energy to mass ratio like conversion efficiency in Joule per tonne (J/Ton) or litre per tonne (L/T) or other efficiency ratios like energy return on investment (EROI), or net energy ratio (NER) for which the energy content of a biofuel is divided by energy required to produce the biofuel (Arviddson *et.al* 2012). The energy content from biofuels is also measured categorically as Energy Units electricity (MWe), (Choudri *et.al.*, 2017).

On a global scale the biofuel production can be measured as total Gigajoules (GJ) of energy produced per year (GJ orPJ/year) (Sims *et.al* 2010) and for liquid biofuels like diesel or ethanol it is measured in Million litres or gallons. 1st generation biofuels are also measured in annual energy yields in terms of Energy (Gigajoules) per Hectare per year (GJ/Ha/yr) or annual collectable yields as Litre per Hectare per year (L/Ha/yr) or tonne per Hectare per year (t/Ha/yr) (.Apart from this it can also be measured as per the area under cultivation(ha) or tons of biomass harvested/produced (T). It may also be noted that the terms used like "energy cost", "energy use", "energy requirement" and "net energy" are overlapping and ill-defined in most of the papers (Arviddson *et.al* 2012).

Tons of biomass harvested or collected

Biomass harvesting and collection is an important step involving gathering and removal of the biomass from field which is dependent on the state of biomass, i.e. grass, woody, or crop residue. The moisture content and the end use of biomass also affect the way biomass is collected. For crop residues, the operations should be organized in sync with the grain harvest as it occupies the center stage in farming process. All of other operations such as residue management and collection take place after so-called grain is in the bin. On the other hand, the harvest and collection dedicated crops (grass and woody) can be staged for recovery of the biomass only. In agricultural processing, straw is the stems and leaves of small cereals while chaff is husks and glumes of seed removed during threshing (Zafar, 2015).

First-generation biofuels are derived from sources such as sugarcane and corn starch. Sugars present in this biomass are fermented to produce bioethanol, an alcohol fuel which can be used directly in a fuel cell to produce electricity or serve as an additive to gasoline. However, utilizing food-based resources for fuel production only aggravates the food shortage problem.[8] Second-generation biofuels, on the other hand, utilize non-food-based biomass sources such as agriculture and municipal waste. These biofuels mostly consist of lignocellulosic biomass, which is not edible and is a low-value waste for many industries. Despite being the favored alternative, economical production of second-generation biofuel is not yet achieved due to technological issues (Naik *et al.* 2009)

Historically, humans have harnessed biomass-derived energy since the time when people began burning wood to make fire. Even today, biomass is the only source of fuel for domestic use in many developing countries. Biomass is all biologically-produced matter based in carbon, hydrogen and oxygen. The consumption pattern of bioenergy varies geographically: - Biofuels in Americas, fuel wood and charcoal in Asia and Africa & combined heat and power generation in Europe.

The estimated biomass production in the world is 104.9 petagrams (104.9 × 1015 g – about 105 billion metric tons) of carbon per year, about half in the ocean and half on land. Based on the source of biomass, biofuels are classified broadly into two major categories. Bioenergy is a versatile energy source as in contrast to other energy sources, biomass can be converted into solid, liquid and gaseous fuels. It is the largest renewable energy source – 14% out of 18% renewables in the energy mix and supplies 10% of global energy supply.

Around the world, woody biomass is used for cooking, production of electricity and heat for industries, towns and cities and production of liquid biofuels. The primary energy supply of forest biomass used worldwide is estimated at about 56 EJ, which means woody biomass is the source of over 10% of all energy supplied annually. Overall woody biomass provides about 90% of the primary energy annually sourced from all forms of biomass (World Energy, 2017).

Area devoted to biomass production

Landscape design for bioenergy networks provides an opportunity to move toward more sustainable systems for the local or regional context where it is being implemented. It offers a means for those affecting and affected by the ecosystem and social services associated with bioenergy systems to engage in a process of assessing and planning how bioenergy might better fit into current energy production and land-use systems (Berndes *et al.* 2008 & Koh et al. 2009).

This engagement entails development and implementation of a spatially explicit, collaborative plan for integrated, sustainable management of landscapes and supply chains. The resulting spatial design is intended to provide a practical plan for developing bioenergy opportunities within given constraints while maintaining or improving the capacity of the system to supply environmental, social, and economic goods and services. When applied to bioenergy, the stakeholders include individuals and groups who are engaged in any part of the supply chain (e.g., land owners, industrial producers, transporters, and users of bioenergy and its precursors) as well as those affected positively or negatively by bioenergy development and use. Legal, customer, and stakeholder demands, environmental and social pressure groups, and competitive advantages all have a role to play. Some combination of these factors can lead to incentives for developing a “collective concern” and acceptance by the community to apply a landscape design approach to achieve more sustainable provision of energy and other services (Dale *et al.,* 2016).

11.3.3. Links to other NCPs

NCP 3-Air quality regulation: Biofuels have been identified as potential climate change mitigation options (e.g., IPCC, 2007b). Even though biofuel production and use can emit significant amounts of GHGs during their whole lifecycle (Hess et al., 2009; Delucchi, 2006) several LCAs have shown (refer to Tables 1 and 2 in the supplementary electronic material) that biofuels can be emit less GHG than fossil fuels during their whole life cycle. Feedstock cultivation can be a particularly polluting due to fertilizers use, land-clearing through fire, other feedstock-specific activities such as su

NCP 4 – Regulation of climate- Several LCAs have suggested that biofuels generally emit less GHG during their full life cycle than conventional fossil fuels. However, LCAs usually do not factor the GHG emissions through direct and indirect LUCC. Biofuels grown on former agricultural land seem to result in smaller carbon debts. Apart from GHG emission, biofuel expansion can affect regional climate through land cover conversion

NCP 6 – Regulation of water quantity - Biofuels exhibit higher water footprints than fossil fuels and other renewable energy sources. Feedstock production relies greatly on fertilizers and agrochemicals that can enter water bodies and potentially disrupt ecosystem functioning. At the same time biofuel production practices can produce effluents with high toxicity and Biological Oxygen Demand (BOD). However biofuel expansion might result in increased water consumption (e.g., de Fraiture et al., 2008; Berndes, 2002). This might result in a competition between food and biofuel production not only for land and labour butfor water as well.

NCP 7 – Regulation of water quality- Fertilisers, agrochemicals and effluent from biofuel refineries can pollute water bodies. However, with adequate management practices some biofuel feedstocks can provide environmentally friendly water sewage treatment and improve water quality in aquifers. However, there is also evidence that biofuel production can sometimes be beneficial to freshwater ecosystem services. For example, some feedstocks can be used to purify wastewater.

NCP 8 – Soils– Culitivation of biofuels depends on soil. The extensive cultivation of the main biofuel feedstocks such as sugar cane, soybeans and oil palm are major causes of soil erosion. Other feedstocks such as Jatropha can improve soil quality and control erosion in marginal lands. In order of decreasing soil erosion hazard17 de Vries et al. (2010) ranked the most commonly used feedstocks as follows: cassava, soybean, sugarcane, sorghum, corn, sugar beet, winter wheat, oil palm and winter rapeseed. Martinelli and Filoso (2008), mention that sugarcane cultivation is a significant driver of soil erosion in Brazil. In fact in several areas of the state of Sao Paulo high erosion rates have been observed in land that is consistently under sugarcane cultivation (Martinelli and Filoso, 2008).

NCP 9 - Natural Hazard impact reduction
One of the major reasons for producing biofuels is to reduce greenhouse gas emissions and to mitigate the effects of global warming produced by fossil fuels. Martinelli and Filoso (2008), mention that sugarcane cultivation is a significant driver of soil erosion in Brazil. In fact in several areas of the state of Sao Paulo high erosion rates have been observed in land that is consistently under sugarcane cultivation.

NCP 12 - food: First generation biofuel feedstocks, such as ethanol from corn or sugar cane, compete directly and indirectly with food production. It is feared that biofuel expansion will compromise significantly food and feed production globally. For this reason, certain countries such as India have enforced a moratorium in the domestic production of biofuels from edible crops. In a similar manner the main feedstock for production of bioethanol in China is low quality corn that is taken from the stockpiles (Zhou and Thomson, 2009).

NCP 13- materials
Biofuels compete with the existing crops for resources and result in trade-offs in primary productivity. It affects the production of other biomass around the region. Biofuel production might also compete with some provisioning services such as fiber and timber. For example Indian Jatropha plantations have been set up on communal land, displacing part of the poor's household needs for food, fuel wood, fodder and timber. Such products often make up the household's largest income source, larger than cash crops and informal cash incomes, and can range from20 to 40%ormore of total household income (Cavendish, 2000; Rajagopal, 2008; Dovie, 2003; Paumgarten and Shackleton, 2003.)

NCP 15 – learning

Ecosystems provide cultural services (e.g., spiritual, aesthetic, educational and recreational services) which are sometimes highly valued in monetary terms (MA, 2005a). Diversity and economic value of bioinspired production.

NCP 17 - Identity

Although biofuel crops receive increasing attention and government support, their expansion may compromise food production and provide questionable climate benefits. However, expansion of the feedstock production for biofuels has been controversial due to potential adverse side effects on natural ecosystems and the services they provide (Gasparatos et al. 2011). Of various drivers, biofuel induced habitat destruction is considered as perhaps the most important threat to biodiversity. Generally speaking, the magnitude of biodiversity loss depends on the type of land that was converted for feedstock production. The conversion of natural ecosystems (e.g., grassland, forest) results in higher levels of biodiversity loss when compared to the conversion of cultivated land (Fischer et al., 2009).

11.3.4. Indicators of NCP (co-) production

NCP	Production Function	Indicator/ Proxy	Rationale/ justification for why this indicator/ proxy was selected	Data set
Cultivated crops	Yield function (tons per ha)	Tonnage of biomass (sugar cane, corn, palm oil) OR land area in biomass production	Direct measure (tonnage) and more widely available (land area)	*FAO*
Collected non-cultivated		Tonnage of fuelwood OR biomass estimates in forests		*FAO (?)*
Animal waste		Numbers of livestock and use rate		*FAO*
First generation feedstock-Cultivated crops (dedicated to biofuels)	Yield function (tons per ha)	Tonnage of biomass (sugar cane, corn, palm oil), other energy crops OR land area in biomass production	Direct measure (tonnage) and more widely available (land area). Data on Agricultural production available	*FAO* IEA/OECD
Second generation feedstock-Lingo-cellulosic feedstock$_1$	Biomass yield from dedicated feedstock (from vegetative grasses and short rotation forestry produce)	Yield (production) in tonnage OR Biofuel yield in Joules or Liters		*FAO* *IEA/OECD*
Second generation feedstock-Lingo-cellulosic feedstock$_2$	Biomass yield from residues and byproducts Biomass yield from waste	Biofuel yield in Joules or Liters from agricultural/horticultural residue, forestry industry residue, other organic residues or by-products from various industries/process Biofuel yield in Joules or Liters from industrial effluents and/or municipal solid waste		

Third generation feedstock-Algae/microalgae	Biomass yield from algae/microalga e	Biofuel yield Joules or Liters from algal/microalgae biomass		

11.3.5. Trends in Co-Production

11.3.5.1. General (across all units of analysis)

Given current trends of rapidly increasing population size and energy usage per capita across the world (International Energy Outlook, 2011), and the related need for increased food production (Smith et al., 2010), it is unlikely that power demand will decrease or that more land (or even anywhere near as much land) could be used for bioenergy than considered here without converting protected land (P o g s o n *et al.* 2013). Pogson and his team also conclude that the production costs for many aspects of renewable power are likely to decrease as technologies mature, and it is likely that policies which target the effects of carbon emissions will also effectively reduce the cost of renewable sources due to their potential for carbon mitigation.

Wildfires are an increasingly important pathway of energy release from land ecosystems, so Veron *et al.* (2012) proposed that the controlled combustion for energy production, based on the diversion of biomass that would eventually burn in wildfires. Biomass is shown to offer only moderate power-generating potential, and would satisfy less than half of current demand even if all suitable existing arable land were used to grow bioenergy crops. However, bioenergy can be cheap to generate given current economics, and is able to remove atmospheric carbon in some cases if coupled with carbon capture and storage (P o g s o n et al. 2013). Since land-based bioenergy is also restricted by the need to grow food for an expanding population,
and technological developments are likely to greatly increase the viability of other renewable sources, the role of land-based bioenergy appears relatively limited and short-term.

- ***Spatial variance*** (& why):

Contributing to GHG emissions, biofuel-driven agricultural expansions can also lead to land-use conflicts among different stakeholders. There has been substantial increases in cultivated area for all major biodiesel feedstocks, including soybean in the US (33.3–45.3 million ha), sunflower seed in Russia (25.7–28.1 million ha), rapeseed in China (10.6–14.3 million ha), and oil palm in Malaysia (0.1–1.8 million ha). Political instability in oil-rich regions, tighter oil supplies, and rising oil prices have prompted many countries to diversify their energy portfolio. Biofuels have gained popularity as they allow both a reduced dependency on oil imports and can be promoted as 'clean energy' alternatives, thereby satisfying both energy security
and environment (i.e., climate change) agendas

- ***Degree of certainty*** (& why):

There are global implications for the shift towards biofuels, net positive GHG emissions, threats to forests and biodiversity, food price increases, and competition for water resources as the key negative impacts of biofuel use.

11.4. Impacts on good quality of life

11.4.1. Different types of value

11.4.1.1. What is the NCP contribution

The contribution of biofuels production and use has to be looked over in a broad sense. It is very much context specific and any generalization may lead to misinterpretation and eventually bad policy decisions. The environmental costs and benefits associated with biofuel production depend on which, where and how it is being produced and the fuels displaced, as well as alternative disposal of the raw materials. For instance, some potential feedstock material such as agricultural or forest wastes are otherwise burnt onsite while other biomass may have productive usage like forage, bedding or other fiber product3.

Cellulose-based biofuels affect the following environmental aspects:

Soil Quality: Biofuels production impacts cropping patterns in the area. Therefore, creating competition with existing crops for soil minerals, soil moisture and organic matter. Apart from this certain biofuel species along with their choice of harvesting (and other management)practices and application of fertilizers soil quality in terms of mineralization, mummification, water holding capacity, nitrogen fixation cycle, carbon exchange capacity, phosphorous availability and eutrophication potential is affected.

Water Quantity and Quality: Water quality of the region is impacted owing to biofuel production factors like choice of species, upstream agricultural practices, application of fertilizers/pesticides/herbicides, irrigation; post-harvest processing or other processes related to its synthesis. The potential effects related to these are eutrophication, sediment loading, habitat degradation, siltation, toxicity and portability, infiltration capacity, water quality reduction, water availability, hypoxia.

GHG Emissions: Biofuels owing to their choice of crop species, use of fossil fuels usage throughout (at various stages of) their supply chain, N fertilizer usage, liming can affect the net GHG emissions balance and hence affect climate change in the long run.

Biodiversity: Biofuels contribute to the trade-offs in the biodiversity dynamics of the region depending on their choice of crop species, regional land use patterns, management practices and native species.

Productivity: Primary productivity is affected due to biofuel production in the region as the competition for resources increase in the area. This results in changes in trade-offs and overall balance which then futher affects climate change and nutrient cycling.

Biofuels affect the following socio-economic aspects:

Energy security/access to energy: Certain biofuel production practices can promote energy security both atthe national and the local level. Small scale biofuel projects have been successful in providing rural populations in developing nations with reliable access to energy, e.g., through rural electrification projects. Food security/access to food: The increase in food prices during the past few years has partly been attributed to the biofuel-food competition. The highest increases in food prices were observed in developing nations and were drivers of social unrest (food riots).

Rural development: The net contribution of biofuels to income and rural employment depends on the opportunity cost in terms of foregone alternative uses of land, technology, labour and capital.

Biofuel policies often aim to promote rural development by supporting rural employment but the positive or negative impact of biofuel production (and its magnitude) depends greatly on the kind of biofuel production system adopted (e.g., large plantations vs. small holders). On the other hand, there is evidence to suggest that small scale biofuel initiatives can contribute positively to human wellbeing through better access to energy, capacity building, poverty reduction and rural development.

Health: Atmospheric emissions associated with biofuel production and combustion can affect human health. Pesticides and other agrochemicals that are used during feedstock production are also potent health threats. The manual and intensive nature of jobs associated with feedstock production, particularly in developing nations, can also impact health in a negative manner.

Land tenure: There are numerous examples where the access of poor people on land has been compromised through displacement of poor families, concentration of land to powerful actors, loss of land rights through coercion/lack of information and aggressive land seizures.

Gender issues: The risks of biofuel expansion might be gender differentiated with women being more likely to face the negative impacts associated with biofuel expansion. However there are also several cases where small and large scale biofuel initiatives have contributed to the wellbeing of women. Understanding the

Cellulose-based biofuels contribute to various environmental and socioeconomic aspects. In terms of MEA classification of Ecosystem services, contribution of biofuels can be as follows:

1. Provisioning services: livelihoods or employment generation at different stages of its supply chain, food, fiber, biofuel feedstock (biomass), water provisioning (drinking water)
2. Regulating services: water purification, carbon sequestration and climate regulation, pest-control, pollination and seed dispersal
3. Cultural services: recreation

11.4.1.2. How do we measure contribution?

Biophysical measures in terms of effect on environment in physical quantities like units of carbon sequestered or equivalent CO2 offset, soil organic matter content of the agricultural field, nitrogen or phosphorous content, units of water used, suspended material in local streams/water samples of the region, fertilizer/herbicide/pesticide concertation in the local streams.

The contribution of biofuels can also be done through Economic measures (market-based methods) like contribution to economy (GDP), market share or trade volume, changes in the prices of biofuels and other commodities (like food prices or oil prices), trends in market price of biofuels, investments made by public and private sector in biofuel industry/production/technologies, return on investment in biofuels. Among the non-market based methods, contribution can be measured through production function, hedonic pricing, willingness-to-pay, contingent valuation and replacement cost method. A detailed cost-benefit analysis of the biofuels in terms of energy generation scenario, emission offset scenario, ecosystem services/disservices generated can also help measuring net contribution.

To assess the contribution to socio-cultural aspect of the economy one can look at employment generated by biofuels at different stages of biofuel production and supply chain, gender equity in employment, measure effects on food security and access to energy.

According to Gasparatos A. et al. (2018) that despite emerging research on biofuels and ecosystem services , there are still important knowledge gaps. These gaps need to be bridged in order to tap the full potential of the ecosystem services approach for assessing biofuel sustainability. Gaps include the lack of (a) knowledge about the ecosystem services impacts of some biofuel production systems/practices; (b) appropriate methodologies and tools to unravel biofuel trade-offs; (c) understanding of the positive or negative policy implications when employing an ecosystem services perspective for assessing biofuel sustainability.

There exists considerable evidence about the impact of biofuel production and use on ecosystem services and human wellbeing; the links between changes in the flow of ecosystem services from converted biofuel landscapes, and human wellbeing
the poverty alleviation potential of biofuels in developing countries.

11.4.2. Indicators of NCP impact

Value type	**Indicator/ Proxy**	**Rationale/ justification for why we this indicator/ proxy was selected**	**Data set**
Direct use by burning	Population directly reliant on biomass		*Un? World Bank ?*
Electricity	KWH x price		*IEA*
Liquid fuels	Tons of oil equivalent x price		*IEA*

11.5. Summary

Although biofuel crops receive increasing attention and government support, their expansion may compromise food production and provide questionable climate benefits. New perspectives on which ecosystems should be targeted and how they should be managed to limit the trade-offs among energy generation, food production, and environmental protection are needed. However, expansion of the feedstock production for biofuels has been controversial due to potential adverse side effects on natural ecosystems and the services they provide (Gasparatos et al. 2011).

Veron et al. (2012) proposed that the controlled combustion for energy production, based on the diversion of biomass that would eventually burn in wildfires, provides an immediate opportunity to reduce fossil-fuel use and its associated greenhouse gas (GHG) emissions and satisfy the growing energy needs of some developing economies.

Encouraging production of biofuels may lead to a net biofuel carbon debt, due to land use change, which will be much more in magnitude than these fuels can neutralize (Fargione et. al., 2008). It will also be in direct conflict with the food production and will require land diversion (Koh *et al*.,2008).

Besides, the authors also investigated that increase in global biodiesel production may result in potential habitat and biodiversity losses due to intensive cultivation in biodiversity hotspots. Also unmonitored intensification may threaten the endemic species of the region. Further demand for biofuels and resulting impact on food prices may undermine conservation efforts by superseding existing incentives for conservation, increasing opportunity costs and thus reducing motivation of the farmers to invest in environmental schemes.

Another threat which may unfold with the increased production of biofuels in of water crisis. Irrigation, globally, is one of the major sector of water consumption. However, the amount of water required for each crop depends on type and location of the crop being cultivated, biofuels will compete with the existing crops for the water resources which might contribute to rising water demands1. Also looking at the synthesis process, bio-refineries consume 4 gallons of process water for each gallon of ethanol produced. The amount of water required to produce 100 million gallons of bioethanol per year would use the equivalent of annual water supply for a town of 5000 people. While in comparison, petroleum refineries use 1.5 gallons of water for producing 1 gallon of oil (Pate *et al.,* 2007). Depending on the water availability scenario of the regions, the effect of this dilemma will vary across the globe. Especially at the local level, if the water supply is already stressed the additional burden will be a matter of concern1.

The silver lining in biofuels have to be seen and innovative solutions need to be evolved. Some solutions like cultivation on marginal or degraded lands, high diversity mixture of grassland species can provide better bioenergy yields, use of best technology to produce/synthesize biofuels that reduce GHG emission during the process with minimal resource (water and energy) usage, agroforestry interventions, and finding other high yielding and alternative sources of biofuel extraction1 might be the way forward for the present times.

	Potential Nature's Contributions	Output of the joint production	Impact on good quality of life
Indicator	(a)Land suitability and extent of bioenergy crop and livestock producing and harvesting areas (b) Diversity and abundance of species for bioenergy use	(a) Energy content of bioenergy crops (b) Tonnage of animal waste used for energy	(a) Increased energy security (b) Revenue from bioenergy production
Trend During the last 50 years: 2 = Major increase (>20%) 1 = Increase (5% to 20%) 0 = No change (-5% to 5%) -1 = Decrease (-20% to -5%) -2 = Major decrease (< -20%)	**(a) Land suitability and extent of bioenergy crop and livestock producing and harvesting areas (2):** It is estimated that the land used for bioenergy production increased between 2004 and 2008 from 13.8 million hectares (Mha) (IEA 2006) to 33 Mha, and in 2008 representad about 2.2% of global cropland (Fargione et al 2010). In 2005 the World Energy Council estimated the world's generating capacity from biomass to be at least 40 GW per year, larger than that from any other renewable resource except for wind and hydropower. **(b) Diversity and abundance of species for bioenergy use (2) :** Almost all of the commercially available biofuels today are produced from either starch- or sugar-rich crops (for bioethanol), or oilseeds (for biodiesel). Other sources include perennial grasses, wood, macroalgae, and agricultural, forestry, or	**(a) Energy content of bioenergy crops (1):** The energy from biofuels can be measured through five energy indicators viz. fossil or primary energy, secondary energy, cumulative energy demand, net energy balance and total extracted energy. The estimated biomass production in the world is 104.9 petagrams (104.9 × 1015 g – about 105 billion metric tons) of carbon per year, about half in the ocean and half on land. **(b) Tonnage of animal waste used for energy (2) :** The manure from a dairy milking 200 cows produces as much nitrogen as is in the sewage from a community of 5,000-10,000 people. The annual litter from a typical broiler house of 22,000 birds contains as much phosphorus as is in the sewage from a community of 6,000 people (USEPA, 2004).	**(a) Increased energy security (1):** Biofuels have gained increasing attention as an alternative to fossil fuels for several reasons, one of which is their potential to reduce the greenhouse gas (GHG) emissions from the transportation sector. The main drivers behind the growth of biofuels are (i) energy supply security (ii) Support for livelihoods for rural community and agricultural industries, (iii) Reduction in dependence on fossil fuels and oil imports, and potential reduction in GHG emissions (Sims et. Al., 2010). **b) Revenue from bioenergy production (1) :** The net contribution of biofuels to income and rural employment depends on the opportunity cost in terms of foregone alternative uses of land, technology, labour and capital. there is evidence to suggest that small scale biofuel initiatives can contribute positively to human wellbeing through better access to energy,

	municipal wastes. The grass species for cellulosic ethanol production include switchgrass, miscanthus (Miscanthus spp.), reed canary (Phalaris arundinacea), and giant reed (Arundo donax) (Lewandowski et al., 2003). Forest plantations and agroforestry systems also serve as potential sources of cellulosic feedstocks for bioethanol production.		capacity building, poverty reduction and rural development. Biofuels often make up the household's largest income source, larger than cash crops and informal cash incomes, and can range from 20 to 40% or more of total household income (Cavendish, 2000; Rajagopal, 2008; Dovie, 2003; Paumgarten and Shackleton, 2003.) Rising fuel prices coupled with concerns about carbon emissions are making biofuel production more cost competitive and attractive (Koh et al., 2008).
Spatial variance 3 = opposite trends in different regions 2 = same directional trends in different regions but of contrasting magnitude 1 = similar trends all over the world	**(a) Land suitability and extent of bioenergy crop and livestock producing and harvesting areas (2) :** While the current main producers of biofuels, the USA, EU and Brazil,can be expected to remain key players, plans for the development of bioenergy especially in China and India suggest that these countries will play a larger role in the future (Gallagher 2008), and changes in the types of biofuels used mean that other countries such as Indonesia and Malaysia, by far the largest producers of palm oil, may also increase their roles. There has been substantial increases in cultivated area for all major biodiesel feedstocks, including soybean in the US	**(a) Energy content of bioenergy crops (1):** Energy usage or energy content is usually measured in Joules (J) or similar units like (GJ, MJ or PJ) and /or with energy content in percentages (Choudri *et.al* 2017). It is also measured in energy to mass ratio like conversion efficiency in Joule per tonne (J/Ton) or litre per tonne (L/T) or other efficiency ratios like energy return on investment (EROI), or net energy ratio (NER) for which the energy content of a biofuel is divided by energy required to produce the biofuel (Arviddson *et.al* 2012). The energy content from biofuels is also measured categorically as Energy Units electricity (MWe), (Choudri *et.al.*, 2017). **(b) Tonnage of animal waste used for energy (1)**	**(a) Increased energy security (1):** Traditional biomass, primarily for cooking and heating, represents about 13 percent and is growing slowly or even declining in some regions as biomass is used more resourcefully or replaced by more modern energy forms. **(b) Revenue from bioenergy production (1) :** Some of the recent estimates suggest that biomass energy is likely to make up one third of the total world energy mix by 2050. Infact, biofuel provides around 3% of the world's fuel for transport. People thus engages in this process will earn livelihoods and revenue in exchange.

	(33.3–45.3 million ha), sunflower seed in Russia (25.7–28.1 million ha), rapeseed in China (10.6–14.3 million ha), and oil palm in Malaysia (0.1–1.8 million ha). **(b) Diversity and abundance of species for bioenergy use (1)**	The USDA estimates that more than 335 million tons of "dry matter" waste (the portion of waste remaining after water is removed) is produced annually on farms in the United States, representing almost a third of the total municipal and industrial waste produced every year. Animal feeding operations annually produce about 100 times more manure than the amount of human sewage sludge processed in US municipal wastewater plants. One dairy farm with 2,500 cows produces as much waste as a city with around 411,000 residents.	
Variance across user groups 3 = opposite trends for different groups 2 = same directional trends for different groups but contrasting magnitudes 1 = similar trends for all social groups	NA	NA	**(a) Increased energy security (1):** The contribution of biofuels production and use has to be looked over in a broad sense. It is very much context specific and any generalization may lead to misinterpretation and eventually bad policy decisions. The environmental costs and benefits associated with biofuel production depend on which, where and how it is being produced and the fuels displaced, as well as alternative disposal of the raw materials. For instance, some potential feedstock material such as agricultural or forest wastes are otherwise burnt onsite while other biomass may have productive usage like forage, bedding or other fiber product3.

			(b) Revenue from bioenergy production (1) : To assess the contribution to socio-cultural aspect of the economy one can look at employment generated by biofuels at different stages of biofuel production and supply chain, gender equity in employment, measure effects on food security and access to energy.
Degree of certainty 4 = **Well established**: Robust quantity and quality of evidence & High level of agreement 3 = **Established but incomplete**: Low quantity and quality of evidence & High level of agreement 2 = **Unresolved**: Robust quantity and quality of evidence & Low level of agreement 1 = **Inconclusive**: Low quantity and quality of evidence & Low level of agreement	**(a)** Land suitability and extent of bioenergy crop and livestock producing and harvesting areas **(2) :** There are two principal avenues for increasing the land available for producing biofuel feedstocks without adverse impacts on other forms of agricultural production, i.e. (i) through conversion to cropland of land not currently under agricultural production (including pasture). (ii) through intensification of production on existing agricultural land so that biofuel crops can be grown while food crop yields remain the same and no further land is converted. **(b)** Diversity and abundance of species for bioenergy use (**3**) **:** Bioenergy is renewable energy made from materials derived from biological sources. Timber, crop residues, and other biological energy sources are important for more than two billion people (Schiermeier et.al, 2008).	**(a) Energy content of bioenergy crops (3):** There are global implications for the shift towards biofuels, net positive GHG emissions, threats to forests and biodiversity, food price increases, and competition for water resources as the key negative impacts of biofuel use. **(b)Tonnage of animal waste used for energy (3)** On a global scale the biofuel production can be measured as total Gigajoules (GJ) of energy produced per year (GJ orPJ/year) (Sims *et.al* 2010) and for liquid biofuels like diesel or ethanol it is measured in Million litres or gallons. 1st generation biofuels are also measured in annual energy yields in terms of Energy (Gigajoules) per Hectare per year (GJ/Ha/yr) or annual collectable yields as Litre per Hectare per year (L/Ha/yr) or tonne per Hectare per year (t/Ha/yr) (.Apart from this it can also be measured as per the area under cultivation(ha) or tons of biomass harvested/produced (T).	**((a) Increased energy security (3):** The contribution of biofuels production and use has to be looked over in a broad sense. It is very much context specific and any generalization may lead to misinterpretation and eventually bad policy decisions. **(b) Revenue from bioenergy production (3):** According to Gasparatos A. et al. (2018) that despite emerging research on biofuels and ecosystem services , there are still important knowledge gaps. These gaps need to be bridged in order to tap the full potential of the ecosystem services approach for assessing biofuel sustainability.

Two to five most important papers supporting the reported trend	1. Koh, L. P., & Ghazoul, J., (2008). Biofuels, biodiversity, and-people: Understanding the conflicts and finding the opportunities. Biological Conservation, 141, 2450-2460. 2. Gasparatos A., C.Romeu-Dalmau, G.von MaltitzF.X.JohnsonC.B.JumbeP.StrombergK.Willis. Using an ecosystem services perspective to assess biofuel sustainability. Biomass and Bioenergy. Volume 114, July 2018, Pages 1-7. 3. Editorial. Using an ecosystem services perspective to assess biofuel sustainability. Biomass and Bioenergy. Biomass and Bioenergy xxx (xxxx) xxx–xxx. 4. Thomas B. , Markus Biberacher , Sabine Gadocha, Ingrid Schardinger . 'Energy landscapes': Meeting energy demands and human aspirations. b i o m a s s and b i o energy 5 5 (2 0 1 3) 3e1 6. 5. P o g s o n M. , H a s t i n g s A., and SmithP. How does bioenergy compare with other land-based renewable energy sources globally? GCB Bioenergy (2013) 5, 513–524, doi: 10.1111/gcbb.1.2013 6. IEA Bioenergy, 2007. Potential contribution of bioenergy to the world's future energy demand, www.ieabioenergy.com.

11.6. Search methodology

(1) related to the NCP name.

Biomass, Bioenergy, Biofuels, Ecosystem services, Biodiversity, Human wellbeing, Millennium Ecosystem Assessment, Biodiesel, Ethanol, Energy crisis, Oil price, Food crisis, Water crisis, Energy Security, Adaptive management Biofuel Planning, Resource management, Scale, Trends, Stakeholder, Energy Reports, First generation biofuel, Second generation biofuel, biofuel sustainability, energy and health.

(2) related to the dimension of value.

Bioenergy and human wellbeing, Bioenergy and pollution, biodiversity and bioenergy, energy security, animal waste used for energy, regulation, provisioning and Cultural services, opportunity cost of times

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12. NCP 12: Food and feed

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12.1. IPBES Definition:

Production of food from wild, managed, or domesticated organisms, such as fish, bushmeat and edible invertebrates, beef, poultry, game, dairy products, edible crops, wild plants, mushrooms, honey

Production of feed (forage and fodder) for domesticated animals (e.g. livestock, work and support animals, pets) or for aquaculture, from the same sources

12.2. Why is this NCP important?

Food for humans is a vital requirement of human existence. The plant, animals, fungi and other biodiversity we eat provide us with nourishment enabling healthy lives. They are the centerpiece of meals shared amongst family, relatives, and friends and food is amongst the most notable elements of culture with foods defined by typical ingredients, flavors, and preparations. Food includes both the foods we consume directly, and the feeds we produce for raising livestock. While biodiversity, from the diversity in farms and fields, to the dietary diversity we consume are key to this NCP, we must also recognize that human appropriation of land and water for food production is the single largest driver of environmental degradation, including wild biodiversity loss (Foley et al. 2011, Springmann et al. 2018, Tilman et al. 2017). Biodiversity conservation and food security are thus two intricately linked subject areas (Tscharntke et al 2012, Wittman et al. 2017). What food we produce (Tilman and Clark 2014), how we produce it (Bennet et al, 2017, Garbach et al 2017), and where we produce it (Tilman et al 2017) impact global dietary health, and our capacity to conserve biodiversity.

Food and Dietary health

Of the 17 ecosystem services evaluated in the Millennium Ecosystem Assessment, food production was one of few that showed net increases (MEA 2005). Food supply and demand can be simplified as the total amount of food produced globally, while demand from a purely biological point of view can be reduced to the per capita food consumption needs of present and future populations. From a purely biophysical perspective, food quantity (±2500 kcal per person^{-1} day^{-1}) from a diversity of species (nuts, legumes, fruits, vegetables, animal or plant-based proteins, fungi) defines balanced diets that are required for human wellbeing. Yet diet has become the single greatest driver of premature mortality globally with more than 800 million people sufferimg from hunger and malnutrition, while one billion more suffer from being overweight or obese (GNR 2017, Zerbe 2010, Fanzo et al. 2013). Food production has increased exponentially during the past eight decades, keeping up with demand following both population growth, and increased economic well-being of global populations. Current FAO estimates are that global food production capacity is sufficient to meet demand, both of today's population and of an anticipated 2050 population of 9.5-12 billion.

Food and cultural identity

Food defines culture and is the most direct link between nature and human physical, social, emotional, and cultural well-being. As such, food cannot be discussed as a solely biophysical element of well-being (dietary health). Numerous species, consumed as foods, are cultural keystones whether salmon in Native American diets, the three sisters (rice, bean, and squash) of Mayan and Aztec cultures, rice in South East Asia and Madagascar, Cassava for Amerindian tribes or Taro in Pacific Islands. Regionally specific foods define regional peoples and cultures - both traditional and modern. Foods defines identity, origin stories, ceremonies and art (Turner et al. 2013). Land races developed locally are food sources which have a significantly high relational value. In most cultures, items that compose food systems and diets, are culturally linked and determine food consumption patterns including the diversity of species used and related social activities. The latter include seed social exchange networks which affect biodiversity of agroecosystems; sets of crops cultivated are in addition closely linked to cultural identity. Many studies show the extent to which social exchange networks and other ways of eating specific food determine the biodiversity on people's plates and how this is shared at integrated levels from local to global (Pautasso et al 2013, Coomes et al. 2015). Food systems reinforce community identity and bonds. Food is often at the heart of human celebrations, irrespective of culture. Social bonds are reinforced by joint food preparation and sharing. Globally cultures are recognized by signature foods frequently specific to regional crops, varieties, or cropping systems. Religious events are marked by food offerings, shared meals, or animal sacrifices across all continents. Ingredients and recipes are often tied to landscapes such as the Satoyama in Japan, and evoke images of places, ecosystems where foods are produced and the knowledge and know-how associated withfood production.

Food and Access and Equity

Food supply at the global level faces the major issue of unequal rights of access to land due to different levels of recognition of different property regimes. Indeed, small -scale biodiversity-rich agricultural systems under common property regimes and customary laws defining access to resources and practices are often less recognized at national levels than-low-biodiversity industrial production systems that acquire private property regimes. Traditional agroecosystems, generally governed by Indigenous Peoples and Local Communities (IPLCs), fall within community or common property types of lands, that face major issues of land grabbing by powerfull sometimes multinational industrial food production development programmes. Food supply thus raises issues of unequal rights to land by different stakeholders with differential voices and level of power in different economic and political arena . There are many known examples today such as palm oil plantations, production of animal feed (e.g. soya bean),and biofuel (e.g. sugar cane) that greatly affect local small scale food production systems

How Food is Produced

Terrestrial food supply is estimated as the per unit area food production capacity of cultivated and harvested lands. Production capacity is a function of local environmental condition by management interventions by crop in question, as well as diets required, in relation to demands at integrated scales, from local to global. Indeed food supply is part of major exchange networks. Decisions made locally are led by global forces and demand, although local decisions can also be made to feed people locally. For example coffee and cacao, among the major food consumption items at the global level, are mainly produced in small scale agroforestry systems in tropical regions (Wolff et al. 2017).

Major Challenges

Major challenges in ensuring both food supply and habitat for biodiversity quantity center around (1) diets, and dietary shifts determining the quantity and quality of food produced, (2) terrestrial and aquatic areas appropriated for food production, (3) efficiency of food, and (4) food waste and loss. Additional dimensions related to these major levers include whether and how wild and agricultural biodiversity are integrated into production systems; land tenure and access to land, and the employment opportunities (quality and quantity) offered by food production, processing, preparation, and waste management. During the past six decades, increased land in production, and improved production efficiencies have been the major means of ensuring adequate food supplies to meet aggregate demand from growing global populations. However, the well-known inequities in the global food distribution system determine that many people are undernourished today despite overproduction of food at the global scale (Alexiades 2004).

Sparing/Sharing

Taken in the context that food production (supply) obtained from conventional industrial production systems is the primary driver of biodiversity loss globally – a growing body of research is concerned with overly simplistic measures of food production and food consumption (DeFries et al. 2015), as well as with other models of food production based on agro-ecological production systems that have been developed historically by Indigenous and Local communities (IPLCs) within smallholders and family farms (Altieri & Toledo 2011., Altieri et al. 2012). There is a shift in how smallholders and family farmers are viewed: from being a part of the hunger problem, to now being central to its solution (Graeub et al. 2013). Land-sparing and land-sharing characterize a key debate in the biodiversity community concerning food production Perfecto and Vandermeer 2010). Land-sparing makes the case that in order to feed a growing global population, food production should be intensified in productive regions, thus sparing intact ecosystems from agriculture. Land sharing in contrast recognizes key NCP's provided to agriculture (pollination, pest control, soil fertility) and makes the case that more biodiversity is conserved when conservation in embedded in agriculture (e.g. agroforestry, agroecology). Such hypotheses are being tested by global modelling efforts to identify trade-offs between species conserved, land cultivated and food produced (Tilman and Clark, 2014, Springmann et al. 2017) and on the other hand significant ecological and social studies that looks at ecology and social issues at other scales than those that are considered in global modelling (XXX) . The global agricultural system provides food for billions of people, yet 800 million people are still chronically hungry and 2 billion suffer from micronutrient deficiencies [*FAO*, 2017]. While these numbers remain alarmingly high, they do reflect some progress. Undernourishment has decreased substantially since the 1990s, both in absolute numbers and as a percentage of the global population (from ~19% to ~11%) [*FAO*, 2017]. Food with low dietary quality (high in meat, sugar, salt content) and diversity (particularly fruits, nuts and seeds) has become the primary driver of premature mortality globally (Global Nutrition Report 2016). The combined negative impacts of food production and consumption on human and environmental health emphasizes that changes on the supply side (increasing production efficiency in existing food producing lands), with reduced food loss, food consumption, and dietary change, will be necessary to ensure that food supply and demand can be met without further disrupting biodiversity conservation and competing land-uses and NCP's (Tilman et al. 2017; Tilman and Clark, 2014). Through emphasizing productivity at the global level, such debates however give little consideration to social-ecological dynamics of small-scale agroecosystems which capitalize on nature's attributions (high biodiversity and low inputs of chemicals) and inputs and the socio-cultural contexts of food productivity, including issues of equity, social cohesion, and market approaches that may reduce negative ecological costs (Fischer et al 2011)..

Reduced dietary diversity

A second major challenge is the global homogenization of diets (Khoury et al. 201#). Globalization has driven the spread of largely reduced, but highly productive crops across the globe – while local diets appears to have diversified, the global impact is one of significant homogenization in diets. Loss of biodiversity in local foods affects directly nature's capacity to supply food. Food and feed supplies that were based on a large diversity of small-scale biodiversity-rich agroecosystems (large diversity of crops and associated species with high levels of genetic resources) generally using low external chemical inputs (Gepts et al 2012), are being replaced by large scale conventional industrialized food production systems with very high productivities, but low farm diversity and low dietary quality of productions. Global assessments suggest that current production systems are too low in diversity, overproducing red meat and grains in general, and dramatically underproducing fruit, vegetables and nuts (Murray et al. Others). Thus the land-sparing, land sharing debate taken within the context of global modelling efforts, while focusing on global food security and conservation targets, most likely masks social-ecological dynamics at smaller scale that need to be understood to address the issue of diversity in global food production approaches. Furthermore global food demands for specific items that are produced mainly in small scale agricultural systems, such as cocoa, coffee and olive oil, may affect local food security through the simple shift in land use and priority given to products for export (Wolff et al 2013)

Food waste and loss

Food waste and loss is a third major challenge. The Food and Agriculture Organization (FAO) estimates that roughly one-third of the edible parts of food produced for human consumption is lost or wasted. This amount accounts about 1.3 billion ton^{-1} year and reflects not only the food processing wastes, but also the "food losses" (Gustavssonet al 2011). A large number of initiatives today aim at transforming these wastes to recover food, but also to produce energy (methane) and other byproducts. Food waste and loss is relevant to the NCP question in that reductions in food waste and loss would reduce pressures for increased land conversion for food.

Marine systems

An extract from the World Ocean Assessment (WOA 2016) emphasizes the importance of the world's oceans for production of fish as food and feed: "According to FAO (2014a) estimates, fish and marine invertebrates provide 17 per cent of animal protein to the world population, and provide more than 20 per cent of the animal protein to over 3 million people, predominantly in parts of the world where hunger is most widespread." Fish (marine, cultured and inland) as food has increased more than the population has increased, i.e. per capita fish supply (consumption) has increased – from 9.9 kg/person in 1960s to 20.5 kg/person in 2017 (FAO 2018). Factors accounting for the increase in fish consumption by humans include: aquaculture, reduced wastage and improved product utilization, improved distribution channels, increased demand, increased income, urbanization and the population increase. In developed countries the increase in fish consumption is driven by supply rather than demand (FAO 2016). External drivers of fish food/feed production include fisheries, climate, market forces (including market-based management approaches) invasive species, pollution, amongst others.

Food demand is bounded by a biophysical nutritional boundary – the need to provide individuals with approximately 2500 calories per day with sufficient nutritional diversity to ensure a healthy and productive life. Food systems globally are able to meet this demand despite persistent regional hotpots where populations struggle to gain access to sufficient quantities of food (malnutrition). The quality of the food supply is receiving increasing attention however – with significant global evidence of poor dietary quality, reduced dietary diversity, and homogenization of food.

Human alterations of ecosystems for food span the entire spectrum for foods that are gathered from nearly intact natural ecosystems, to biocultural interactions that have spanned millennia where it currently is difficult to distinguish between the human, and non-human elements of the landscape (Mace 2014). The Globally Important Agricultural Heritage Sites (GIAHS) managed by FAO exemplify this concept spanning the saffron heritage of Kashmir, the Hani rice terraces in China, or Tunisian Oasis systems to name just a few. In France, the pastoral landscapes of the Pyrenees are difficult for many to imagine in the absence of livestock, as is also the case of the Dehesa oak and black pig forests of Spain. Modern agricultural systems can be designed that share the ecological and food production values of traditional or GIAHS systems. For example, California rice is one of the most productive systems globally, and provides 200 K ha of overwintering habitat for migratory waterfowl, while also serving as the first line of defense against flooding for the City of Sacramento (DeClerck and DeClerck, TEEBAgriFood 2015)

Fish are a large, but underappreciated, component of the global food system (Béné et al, 2015). Although commonly thought of as source of protein, fish's most important contribution to diets is as a rich source of vitamins, minerals and fatty acids, essential to human health and development (Golden et al. 2016, Bogard et al, 2017). The regions in which fish makes the largest contribution to human diets (much of Asia and parts of Africa) are among those where the highest levels of undernutrition are found (Hall et al., 2013). An estimated 845 million people are 'seafood dependent', most of them living in countries in these regions (Golden et al, 2016).

In summary, food as an NCP is deeply tied to our biological, psychological, and cultural well-being.

12.3. (Co-) production

12.3.1. How is this NCP produced?

Wild plant collection, fishing, hunting: Nature supports populations of wild edible species and people have developed various kinds of tools to collect plants or animals (e.g. snails), capture wild animals or harvest wild food products such as honey.

Food is easily oversimplified as yield per hectare – as such there is a clear indication that the supply of food has increased over the course of human history. Whether this is akin to an increase in the food NCP is debatable however as a significant proportion of those increases have come from the replacement of supporting NCPs by drawing on geological reserves (ground water, fossil fuel derived fertilizers), the development and application of synthetic fertilizers, and the chemical rather than biological control of agricultural pests. As such, it is questionable whether food itself is an NCP, or whether the means of food production are based on NCPs, or based on the replacement of NCPs. This is not an either/or question as food production systems range from completely NCP based (hunting and foraging) traditional agrosylvopastoral systems productions that relied heavily on NCPs, to food production systems that are nearly absent of NCPs (green-house production systems, vertical farms, petri-dish meats). As an extreme example, it is debatable whether food produced in Dutch hothouses is an ecosystems service as it is produced in the absence of most environmental variables. On the opposite side, well managed coffee agroforests emphasize and make use of companion tree species as sources of soil fertility, pollination, and pest control (citation).

How food is produced is both impacted by NCPs and impacts NCPs with production systems that are fully or partially dependent on NCPs to produce food (pest control, pollination, water), and that are net providers of, or degraders of NCP (carbon sequestration, water quality, water quantity). As such, how food is produced is more complicated that simply assessing that food is produced (e.g. that supply meets demand). For example, in the case of fish, it is not only quantity, but also the quality of fish that is important in terms of production of fish as a food source - size and condition of fish, and also the "value" of a fish - e.g. table fish (usually high trophic level (predatory) fish, versus forage fish (anchovy, sardine, low trophic level fish, often but not always less desirable for eating, often converted into fishmeal). Production of fish as food for humans is growing at a rate of 3.2% per annum (WOA 2016). This is wild caught fish as well as farmed fish (aquaculture), from the ocean, estuaries, rivers and lakes. In addition, fish is also used to make feed for domestic animals and for cultured aquatic resources (aquaculture). Overall, close to 90% of World fish catches are of marine origin rather than from inland fisheries (FAO 2018).

Biological

Food production is inherently biological and includes contributions from biodiversity at all scales, from field (production) to flush (decomposition and nutrient cycling). It includes NCPs that are the product of evolutionary history (nitrogen fixation, nutrient and flavor values of foods), to services that are provided at annual time scales (pollination and pest regulation). NCPs to and from agriculture range from field scale interactions between species, to landscape scale interactions driven by species movement, or in the case of pests, the disruption of movement between fields. Healthy marine ecosystems will ensure sustainable production of food and feed from the World's oceans. Marine biodiversity acts as a buffer against loss of the ocean's capacity to provide ecosystem services such as food for humans or animal feed (see Worm et al. 2006).

The UNEP TEEB AgriFood program provides a useful framework for considering the myriad of NCPs that contribute to the Food NCP, while also considering the impact of food production on non-agricultural or non-food based NCPs (Figure 3). The TEEB AgriFood framework is useful in drawing attention to the three systems that interact to produce food: the foundation is Biodiversity and Ecosystems (NCP: Nature), which provides employment, food, fuels, fibers as well as cultural identity, recreation space and health to human systems (NCP: People) as mediated by agricultural and Food Systems (NCP: Contribution). The framework clearly also identifies the myriad of NCPs that contribute to food production, in this case labelled as “invisible positive flows” and including pollination, soil formation, nutrient cycling, pest control, genetic diversity, freshwater provisioning, and climate regulation (see summary list below).

Also included in the framework are the impacts of food production on biodiversity and ecosystems most notably the loss of biodiversity through the simplification of ecosystems and agricultural expansion. NCPs frequently impacted by agricultural practices include soil erosion (see the IPBES Land Degradation Assessment), pollution of air, land and water), and climate change. Current assessments indicate that about 80% of all threatened and endangered terrestrial and mammal species are at risk from agriculturally driven habitat loss (Tilman *et al.* 2017).

Co-production through bio-cultural interactions

The large diversity of cultures around the world have developed through history as a result of co-evolutionary processes linking human societies to NCPs that produce food (Mollard & Walter 2008). Development of farming systems since the Neolithic in different parts of the planet have brought unprecedented changes to cultivated biodiversity, domestic animals, and associated wild biodiversity within agroecosystems, which have further shaped landscapes. These processes have in turn transformed human social and political organizations (e.g. Zohary et al. 2012, Willcox et al. 2012, Willcox *2014*). Modern industrialized food productions also shape peoples' habits and ways of interacting with others.

Major crops such as wheat, rice, olive oil, potato, coffee, cocoa, yam and animal products are used at the global level and have been selected and are still under processes of selection locally, in most cases by small farmers who rely heavily on NCPs for their livelihoods (Gepts et al. 2012 for a global overview, Clements et al 2015, Rival & Mckey 2008, in Amazonia, Aumeeruddy-Thomas *et al.* 2017 in the Mediterranean region, FAO report on livestock at the global level (2007) for livestock etc.). It is also acknowledged that the highest levels of agrodiversity still resides in areas where people are still in contact with wild crop relatives (Khoury *et al.* 2016, Castañeda-Álvarez et al 2016), implying a historical and continuous process of selection by farmers living in these regions in addition to local evolutionary processes. It is fully recognized today that Indigenous Peoples and Local Communities are the greatest contributors to the selection of most genetic resources of all major crops and animals that still feed the planet. This includes a large diversity of crops such as rice (Asia and Africa) wheat (Mediterranean region), maize (Meso-America) , tuber crops (South America and Pacific), coffee (Ethiopia, Brazil), cocoa, quinoa etc (Gepts et al. 2012 , Khoury *et al.* 2016, Castañeda-Álvarez et al 2016). Very active farmer seed exchange networks also contribute to the enhancement of this diversity beyond localities (Salpeteur et al. 2017.). At the other extreme of human socio-cultural processes affecting crops diversity, genetically modified crops, or large scale clonal processes with tissue culture for instance represent other cultural paradigms which contribute to food supply, although seeming departing from NCPs.

Post production processes such as food preparation, and food consumption are inherently socio-cultural. It might be argued that there is no single NCP that better defines our relationship with nature, society, and culture than food does. Even in urban areas, where food is not produced locally, food is probably the most and sometimes the only link that people have indirectly with NCPs.

Regions are defined by their cuisines, with cookbooks serving as a unique record of place-based ingredients and preparation methods – which when linked to food cultivation or sourcing methods captures the identity of local ecosystems. While food nourishes from a biological perspective, food culture defines who we are as individuals, as society, and as ethnicities. We define specific cuisines as 'ours', and the sharing of food is the most common means of sharing these identities with others.

Shifting cultivation: a case study

Shifting cultivation, swidden or slash and burn agriculture is a system where plots of forest are slashed and burned, cultivated for a short period and left to fallow for a long period, making use of the forest dynamics and ecosystem services in order to recover the original characteristics and fertility of the soil (Schneibel et al., 2017; Jakovac et al., 2016; van Vliet et al., 2013). This system is practiced essentially by smallholders and is more prevalent in the tropical and subtropical areas of the globe, being one of the dominant land uses in these areas (Central and South America, Africa, South and Southeast Asia, and the Southwest Pacific) (Heinimann et al., 2017, Mukul and Herbohn, 2016, Wood et al., 2016, Sarkar et al., 2015, Van Vliet et al., 2012). A recent global review (Heinimann et al. 2017) found that landscapes under shifting cultivation management summed up to around 280 Mha in 2010 (including plots under management and fallow areas), with the largest share in Africa, followed by the Americas and Asia (Fig. 4). Global data on shifting cultivation is still scarce, because usually this type of practice is categorized as farming by official censuses and it is typically combined with other types of land management (Heinimann et al., 2017). Estimations of the global population relying on shifting cultivation systems fall between 35 million and one billion, although they are inadequate and outdated (Mertz et al., 2009). However, it is accepted that the number of swiddeners in Southeast Asia is between 14 to 34 million people around the 2000's (Mertz et al., 2009), meaning between 2,3 and 5,6% of the local population.

In shifting cultivations systems, household consumption is based on staple crops and complemented in a great share with wild plant and animal species, which tend to be more nutritious than food imported from market networks (Broegaard et al., 2017) and are crucial for household's food security. Traditional staple crops produced by shifting cultivation systems include upland rice intercropped with chilli peppers, cassava or bananas in East Borneo (Indonesia), Malaysia (Mertz et al., 2012) and the whole Southeast Asia (Siahaya et al., 2016); yam and rain-fed taro followed by kava or banana in the Pacific (Blanco et al., 2016); maize, squash and beans in Mesoamerica (Pérez-García and del Castillo, 2016; Schmook et al., 2013); rice in Madagascar (Zaehringer et al., 2016); finger millet, beans, cassava and maize in Central Africa (Grogan et al., 2013); and rice, maize, beans and cassava in South America (Adams et al., 2013; Fraser 2010).

It has also been accepted that shifting cultivation may contribute to biodiversity conservation and ecosystem services (Pérez-García and del Castillo, 2017; Van Vliet et al., 2012), or at least cause a lower impact than other agricultural systems (Wood et al., 2017). When practiced under certain conditions, e.g. long fallow periods and low population densities, forest landscapes under shifting cultivation have a high potential to act as carbon sinks (Van Vliet et al., 2012), and are able to fully recover ecological parameters (Teegalapalli and Datta, 2016) such as tree communities (McNicol et al., 2015) and soil chemical properties (Ribeiro Filho et al., 2015) (sometimes not even affecting soil nutrients - Suryanto et al., 2017; McNicol et al., 2015). Moreover, fallow forests are providers of ecosystem services supporting crop production (erosion control, fertility regeneration and weed suppression) and animal habitat (Fantini et al., 2017; Wood et al., 2016; McNicol et al., 2015a). These systems have been considered a rational choice for forest farmers that live under unequal access to markets, specific cultural conditions or areas of poor soils (Van Vliet et al., 2012), and is often the only source of income in poor areas (McNicol et al., 2015) .

Pastoralism

The commonly accepted definition refers to pastoralism as “the use of extensive grazing on rangelands for livestock production” (FAO 2001). As most rangelands are characterized by a high variability and unpredictability in rain patterns and vegetation cover, pastoralism can be understood as a specialization, among livestock production systems, that takes advantage of these highly variable environments (Krätli et al. 2013: 43). This food production system is based on strategic mobility, through which herders will target grazing areas with the highest nutritional value to their herds, or other places of interest for access to resources or to markets (African Union 2010, cited in Krätli et al. 2013).

Pastoral systems are highly diverse and make use of different biomes across the world. Researchers proposed many criteria to classify pastoral systems, depending on the animal species they rely upon, on the management system they implement, on their spatial location, on the biomes they make use of (Galaty and Johnson 1990, FAO 2001), or on the patterns of mobility they follow (Johnson 1969). The degree of pastoral mobility range from sedentary systems to transhumant (regular movements of herds between fixed areas to exploit seasonal variations of resources), to nomadic (high mobility and variability of movements) (Johnson 1969). Seemingly, livestock production has a varying importance in these systems, some being specialized and relying on livestock production only (such as the Fulbe in the African Sahel for example (Schareika 2003), some associating animal raising to other agricultural and non-agricultural activities. A distinction is usually made between pastoral and agropastoral production systems: pastoralist households rely mostly on pastoralism (some authors have proposed a threshold of 50 percent of gross income or from agricultural income coming from pastoralism to classify households as pastoralists, see Swift 1988, Rass 2006), while agropastoralist households associate livestock to other farming activities (with a threshold of 25-50 % of income from farming and 25 % minimum from pastoralism (Swift 1988, Rass 2006).

Spatial distribution of pastoral systems across the globe

Pastoral and agropastoral systems are found across almost all the biomes on the Earth, from the circumpolar regions (in Scandinavia and Siberia) to the hyper-arid drylands in the tropics. Rangelands may be found in cold, temperate, tropical and arid climates, at a high or low altitude. Table 4 provides a list of the main pastoral areas in the world, with associated domestic species. Species that constitute the basis of pastoral food production systems are mostly ruminants, either large (humped and non-humped cattle, buffalo, yak, reindeer) or small (sheep and goat), but many systems also rely on pseudo ruminants (dromedary and Bactrian camel, alpaga, llamas), monogastric herbivores (horses, donkeys) or, being more rare, on birds (ducks, geese in Southern India).

Most of the pastoralists make use of “open” grazing lands (savannas, grasslands, prairies, steppe and shrublands (Asner et al. 2004), hence the major pastoral areas in the world are related to these rangelands: in Northern, Eastern and Southern Africa, Southern and Northern America, Australia, Central and Northern Asia, Middle-East and Europe. Among open grazing lands, it is estimated that about 26 million km^2 of land is under managed-grazing systems (Asner et al. 2004).

The pastoralists who also graze in forests and cropped areas, such as the van Gujjars in the Himayas (Gooch 2004) are not taken into account here, as there are no estimates of the area of which they make use.

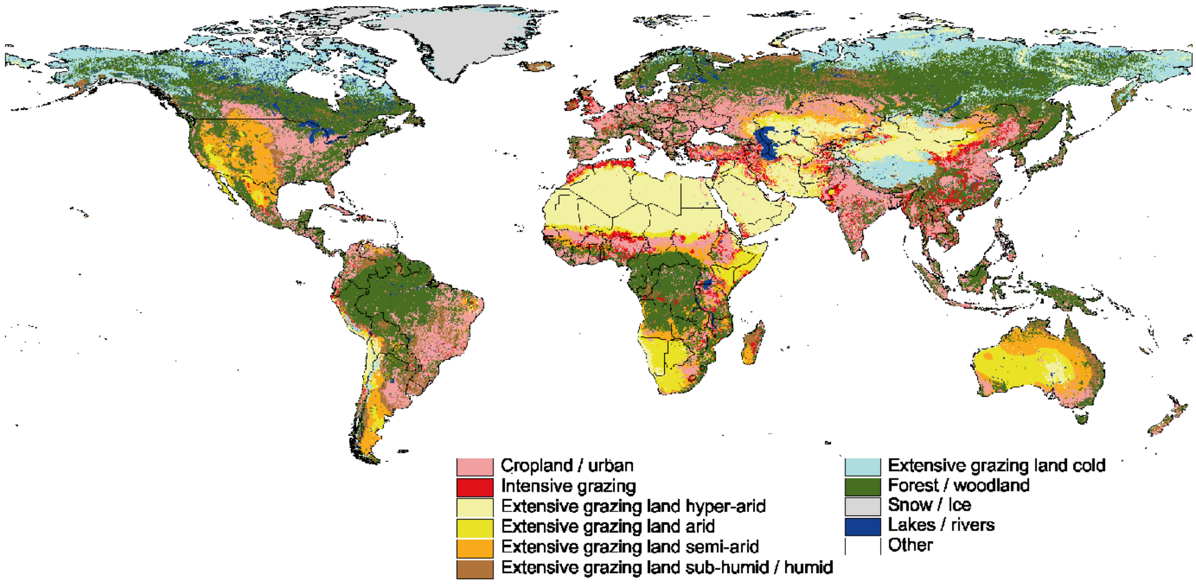

Figure 3. Global map of grazing lands, excluding Antarctica (from Reid et al. 2008: 2). Most of the extensive grazing lands mapped here host pastoral or agropastoral systems.

<u>*Summary of how this NCP is produced*</u>:

- ***Direct***: Nature supports the conditions and biodiversity and processes that allow for production of source material for food and feed
- ***Direct***: Anthropogenic assets (knowledge, practices, technology, worldviews, institutions, trade) interact with nature processes to coproduce food and feed
- ***Indirect***: a large diversity of socio-cultural meanings are associated with food and feed (leisure, recreational fishing or hunting, food preferences, identity)

12.3.2. How is (co)production of this NCP measured?

Terrestrial

Food production is measured as the amount of food produced on a per ha basis. Increasingly however, there have been calls for calorie, or nutrient based measures per unit area (DeFries et al. 2015). Because of its critical role in securing human well-being, food provisioning is well documented including forecasts of future production capacity. However these figures rarely include non-conventional agricultural systems such as large scale complex tropical agroforests that look more like forests than agricultural land, homegardens, shifting cultivation, or pastoralist nomadism etc.

Co-production implies some measures of levels of agrodiversity found across the diversity of agricultural production systems because this would illustrate interactions between anthropogenic assets and biological processes.

Current production levels are monitored by the UN Food and Agricultural Organization (FAO), and in the publicly available FAOStat. We anticipate however that assessments of food production will be an increasingly automated process supported by remote satellite sensing. Measurements of how food is produced remain more elusive, with trends in contributions of supporting NCPs to food production largely missing despite a growing interest in their use.

Field or harvest-based measures of food produced are typically recorded as yield per hectare. Crop based measures are further converted into caloric or nutrition based measures. Comparisons between supply and demand are made on a caloric basis with 2000 calories per person serving as a normative lower threshold, noting varying nutritional needs by age and gender. Crop yield can be further reduced to a nutrition yield per hectare which can complement caloric based measures to assess quality of food produced in addition to quantity.

- Direct measures:
  - Diversity of wild and /or domesticated species involved including varieties and landraces
  - Nutritional value of food
  - Diet preferences
  - Direct or indirect availability of food resources (variable supply chains, traceability of the whole supply chain)
  - Amounts collected (hunting, fishing, collection of wild plants, honey, mushrooms
  - Amount harvested (yield or tonnage)
- Models
  - Relationship of catch or yield to land use, climate,
  - Agricultural productivity models
  - Fisheries models
- Measure is frequently done by marginal impact of contributing NCPs (e.g. marginal contribution to output of pollinators)
- Indicators of the NCP

Terrestrial:

Yields are key measures

Indirect measures can be superficies of land under a specific type of production systems with inferences of number of people who benefit directly from food from these systems

Marine

- Catches are key measures underlying indicators of fish as food supply and the sustainability of the fisheries when compared to relevant benchmarks.
- *Indicators of food supply from the oceans:*
  - Note: Amount and quality are important; Quality indicators are mainly available at a local scale whereas indicators of quantity (amount of fish) are globally available.
  - -Landed catch (capture fisheries production); Aquaculture production; Quality of the fish, shellfish or seaweed stock; indicators to measure species composition; age profile; length profile; percentage affected by disease; mortality rates; Quality of fish in terms of "desirability" - there is often a preference for predatory fish, thus Trophic Level of the Landed Catch may be useful in this respect. A useful reference for generic indicators of ecosystem services that includes provision of food from the ocean is Hattam *et al.* (2015: see Table 2, services 1a and 1b).
- Considering the various indicators of detrimental impacts of fishing, several metrics are used as indicators of a functioning ecosystem that can support sustainable fisheries.
- *Indicators of a functioning ecosystem to ensure food supply:*

The first three indicators listed below were amongst those proposed by the IndiSeas WG (www.indiseas.org) and several have been included now in the core or peripheral sets for IPBES. These are available from 1980 to 2010 or more recent years for 29 exploited marine ecosystems around the world (Coll *et al.* 2016))

  - fish size (mean length of fish in the community) (Shin et al. 2010)
  - trophic level of the surveyed community (Shannon et al. 2014)
  - Proportion of Non-Declining Exploited Species (NDES) in surveys (Kleisner et al. 2015).

- The Large Fish Indicator (proportion of fish (by mass) of the fish community that is larger than a threshhold size), representing the state of the fish community (Greenstreet et al. 2011) is a selected indicator proposed by the Marine Strategy Framework Directive (MSFD; Rombouts et al. 2013).
- Ocean productivity as a measure of ecosystem functioning, e.g. Net primary production (see http://www.science.oregonstate.edu/ocean.productivity/index), or proxies such as Chlorophyll a (for an example see https://earthobservatory.nasa.gov/GlobalMaps/view.php?d1=MY1DMM_CHLORA), zooplankton abundance and community size structure. However, the direct linkages between ocean productivity and fish production are weak as energy transfer through the food web is highly system- and food-web-dependent.

12.3.3. Links to other NCPS

NCP1 – habitat - Aquaculture itself can be detrimental in terms of coastal impacts that include habitat conversion, in addition to pollution of coastal and open sea biomes. Agriculture is a driver of natural habitat loss. There is a whole gradient from antagonistic effects to synergies between agriculture and habitat quality. Similar situations are met in fishing and substrates and between aquaculture and water quality, and in plant and mushroom collection, from subsistence to industrial approaches which affect habitats according to a gradient.

NCP2 – pollination – Most crops rely on pollination. Pollination is important for wild species of interest for food or feed.

NCP3 – air quality – Intensive agriculture – soil erosion – reduces air quality. Agrochemical applications affect air quality.

NCP4 – climate - The provision of food/feed by the ocean is linked to the capacity for the ocean to regulate climate. Conversely, especially in the case of small pelagic fish that are subject to large fluctuations in productivity, climate induces changes in abundance and distribution of fished marine species.

Food production through intensive agricultural production reduces capacity of ecosystems to capture and store carbon and increases emission of green house gases.

Some agricultural systems can mitigate or achieve some compromise between production and regulation of climate. These are mostly agroforestry systems.

NCP5 – regulation of ocean acidification has implications for provision of seafood such as shellfish.

NCP6 – water quantity – Irrigation in agriculture affects waterflow, underground water and freshwater input to the ocean.

NCP7 – water quality - Pollution is a key constraint in the production of food by the ocean (heavy metal contamination for example), and this is often linked to Regulation of Freshwater Quality (part of NCP no. 6).

NCP8 – soils – There is a gradient from agricultural systems affecting soil biota to agricultural systems that maintain soil biota. The general tendency is rather towards the negative side, especially for industrial agricultural systems, whereas agroecological approaches in multiple cropping systems can better conserve soils.

NCP9 – hazards – can affect food production areas; conversely food production can create or exacerbate hazards (e.g. landslides, fire, agrochemical pollution, flooding).

NCP10 – pests – Intensive agriculture decrease pest regulation by nature, whereas low input agriculture increase pest regulation by nature.

NCP11 – energy – also an input to food production – competes with land use for biofuels; affects food price because energy needed for food production; there is a tradeoff/switch from land use for agriculture to land use for biofuels. Residuals of agricultural crops are a source of energy.

NCP 12 Ocean-based production of food and feed is also strongly connected to, and influenced by land-based production of food and feed such as food production from livestock, through feed and fishmeal production, and nutrition (fish oils).

NCP13 – materials – also an input to food production; there is competition between allocating land for producing timber versus grains, for example.

NCP14 – medicine – agricultural systems with chemical inputs are likely to negatively affect human health – leading to new medicines being required (think of food allergies, for example). Agricultural systems with few chemical inputs tend to produce food as well as boosting health. The content of diets and food diversity is likely to affect health. Less homogenous diets are having a detrimental effect on food.

Choices of food production and methods of food production are linked to:

NCP15 – learning – main issues are related to large amounts of food production that come from distant (km) sources i.e. people do not know/appreciate the sources of food. There is a reduction in learning (transfer of knowledge) of the way food is produced in urban societies. IPLCs (Indigenous and local communities) are recognized on the basis of reciprocal relationships with Nature to maintain learning processes in relation to food and feed.

NCP16 – experiences – food throughout all societies are institutions whereby rules and norms of what to eat, how and with whom are elements of culture. Experience with food is also highly dependent upon whether it is food that one produces (direct experience) or whether we are distant users, including experiences of taste and odor. Natural tastes and odor are known to be highly degraded by long distance travels. Conservation practices are important approaches of direct experience with food as well as cooking practices.

NCP17 - identities – people identify with food types and activities around food production especially when involved historically in selecting landraces. Thus agricultural territories and land create special identity bonds owing to co-coproduction of food/feed. Food evokes a sense of belonging, a sense of being part of the process, and often relates to ancestral histories.

12.3.4. Indicators of NCP (co-) production

NCP	Production Function	Indicator/ Proxy	Rationale/ justification for why this indicator/ proxy was selected	Data set	Scale of Measure – space	Scale of measure - time
Food	From summary bullets	Yield per hectare converted to caloric or nutrient yield	*Existing data from FAO Stat on supply function.*	*http://www.fao.org/faostat/en/#home*	National aggregated to global	annual
Food co-production		Agrodiversity and landraces known to	*FAO* *Literature review*			

		date for major crops				
Cultivated	Agricultural area	Remote sensing of croplands				
Cultivated	Aquaculture area	Reported?				
Cultivated	Rangeland	Data on where pastoralists are?				
Cultivated	Levels of biodiversity in different large types of production systems	Biodiversity richness/ types of agroecosystems And where these systems are/ what biomes	*A measure of the range of biodiversity found in large types of agroecosystems, can be found.*	*ICRAF Litterature review*	National to global	
Wild	Amount harvested	Reports on collected high-value items like mushrooms? Bushmeat? Diet surveys?				
Marine:						
Production of fish (for food and feed -wild-caught and cultured)	Quantity of fish as food	Landed catch (capture fisheries production)	*Widely available stats*	*FAO (State of the Word Fisheries) Watson (2017) dataset,* https://www.nature.com/articles/sdata201739/figures/3	Global, regional and on a country basis	1950s onwards
		Aquaculture production	*Indication of "farming" versus wild caught fish*	*Aquaculture production – FAO database ; Fish meal and fish oil use in aquaculture feeds - IFFO:* [*http://www.iffo.net/*](http://www.iffo.net/)	Global, regional and on a country basis	annual
	Production of feed (for domesticated animals and aquaculture)	Quantity of fish produced for animal/aquaculture feed	*Indication of amount of fish harvested that is used indirectly to feed farmed resources*	*FAO and IFFO (http://www.iffo.net/)*	Country basis	
	Quality of fish	Mean length of catch	*Fishing degrades the size structure of the fish community*	*FAO + Fishbase; or local data –*	Global or by ecosystem (country)	1980s onwards

		Large Fish Indicator	*Fishing degrades the size structure of the fish community*	*MSFD – Rombouts et al. 2013*	Regional application so far; global potential	
		TL of the landed catch	*Fishing degrades the size structure of the fish community*	*http://www.seaarounds.org/data/* *FAO + FIshbase; or local data such as at www.IndiSeas.org*	Global or by ecosystem (country)	1950s onwards
	Functioning ecosystem	Mean length of fish in the community	*Fishing degrades the size structure of the fish community*	*www.IndiSeas.org*	Compared across ecosystems	1980s onwards
		Proportion of Predatory fish in the community	*Fishing removes large, predatory fish, changing the food web structure*	*www.IndiSeas .org*	Compared across ecosystems	1980s onwards
		TL of the community	*Fishing removes large, predatory fish, changing the food web structure*	*www.IndiSeas .org*	Compared across ecosystems	1980s onwards
		Proportion of Non-declining species in the surveyed community	*Indicates community changes that may alter ecosystem productivity*	*www.IndiSeas .org*	Compared across ecosystems	Current status
		Net Primary Production (NPP)	*Indicates community changes that may alter ecosystem productivity*	http://www.science.oregonstate.edu/ocean.productivity/index World Ocean Assessment Chapter 5 Figure 1	Global	2003 onwards
	Sustainability of marine food supply	MTI (Marine Trophic Index)	*Fishing degrades the food web*	*http://www.seaarounds.org/data/*	Global	1950s onwards
		Change in mean fish size	*Fisheries degrade community size structure*	*Pauly et al. 2005;*	Global	1950s vs 1990s; can be updated
		Proportion of fish stocks within biologically sustainable levels	*Sustainable fisheries maintain fish stocks at biologically "healthy" levels*	*Costello et al 2012, Costello et al 2016 http://www.pnas.org/content/113/18/5125*	Global, regional	1980s onwards
		Trends in fisheries certified by the MSC	*Indication of sustainable fisheries*	*http://journals.plos.org/plosone/article?id=10.1371/jour*	Selected countries	

				nal.pone.0043765		
		Status of Assessed Fish Stocks	*Indication of sustainable fisheries*	*Costello et al 2012 http://econ.ucsb.edu/~olivier/COHGDL_Science_2012.pdf*	Global, regional	1980s onwards
		IUU	*Indication of unsustainable fisheries*	*Watson 2017*		
	Sustainable fisheries management systems	Ocean Health Index	*Integrates across scientific, social, economic and management to assess ocean health and the benefits derived by humans*	*Halpern et al. 2015*	Country basis – global coverage	Recent years
		EBFM Performance Index	*Integrates across scientific, social, economic and management to assess management effectiveness*	*Pitcher et al. 2009 a and 2009b*	Country basis – global coverage	Recent years
		Fisheries Management Effectiveness Index	*Integrates across scientific, social, economic and management to assess management effectiveness*	*Mora et al. 2009*	Country basis – global coverage	Recent years
		Fisheries Management Index	*Integrates across scientific, social, economic and management to assess management effectiveness*	*Melnychuck et al. 2016*	Country basis – global coverage	Recent years

12.3.5. Trends in Co-Production

12.3.5.1. General (across all units of analysis)

Terrestrial

Cropping systems

Agricultural systems are the largest human use of land. Croplands comprise 1.5 billion hectares of land across the globe, or around 12% of the Earth's ice-free land surface, and pastures utilize another 3.4 billion hectares [*Foley et al.*, 2011]. These land uses have remained relatively constant at 4.9 billion hectares since the early 1990s [*FAO*, 2017]. However, global numbers obscure substantial regional trends; while land in agriculture has decreased in temperate regions, agricultural land increased by 6 million hectares per year across subtropical and tropical regions [*FAO*, 2017]. The largest increases in cropland occurred in Latin America and the Caribbean, Sub Saharan Africa, and Southeast Asia, regions which saw a 15% increase in cropland between 2000–2004 and 2010–2014. Harvested area in major crops has also increased over this period, most substantially for maize and soybean (Table 5), with growth concentrated in Africa, South America, and Asia [*Grassini et al.*, 2013]. Pasture areas vary considerably in their livestock density, and around 1.5 billion hectares of pastures in marginal environments are estimated to be minimally utilized [*Mottet et al.*, 2017].

Crop productivity growth over the past 50 years has helped constrain the footprint of agricultural lands [*Burney et al.*, 2010], however, the extent to which crop yields will continue to increase remains uncertain. Globally, average yields of the four major crops have increased by 10–17% over the past decade (Table 5). Yield gains are unequally distributed [*Ray et al.*, 2013], and, despite historically experiencing yield gains, 26% of maize area, 35% of rice area, 37% of wheat area, and 23% of soybean area are exhibiting stagnant yield trends [*Ray et al.*, 2012]. Hotspots of stagnation include East Asian rice and European wheat [*Ray et al.*, 2012; *Grassini et al.*, 2013]. Yields in many regions of the world remain below their biophysical potential due to a host of management and socioeconomic constraints [*Lobell et al.*, 2009; *Waddington et al.*, 2010; *Mueller et al.*, 2012].

Edible crop production is attributed to human food, to animal feed, and to biofuels. The livestock sector consumes 6 billion metric tons of dry matter from croplands and pastures, and consumes one-third of global cereal production [*Mottet et al.*, 2017]. Livestock utilize large amounts of land area of limited suitability for crop production [*Mottet et al.*, 2017], but the use of feed competes with using crop production for direct human consumption. Livestock, especially ruminants, are relatively inefficient at converting feed calories into edible calories, and conversion inefficiencies reduce the possible number of people fed per cropland hectare [*Cassidy et al.*, 2013]. Between 2000 and 2010, global crop calories allocated to biofuel production increased from 1 to 4% [*Cassidy et al.*, 2013].

Table 4. Regional distribution of cropland and pasture from 2010–2014, and the percentage change from 2000–2004. Data are from the UN Food and Agriculture Organization. Croplands defined using the FAO category "Arable Land and Permanent Crops" and include land planted in annual and perennial crops, gardens, and temporary meadows, and does not reflect all potentially cultivable lands. Pastures are defined using the FAO category "Permanent Meadows and Pastures" and includes all land used for five years or more for herbaceous forage crops, and includes both natural meadows and planted pastures.

region	cropland area (Mha) 2010–2014 (% change from 2000–2004)	pasture area (Mha) 2010–2014 (% change from 2000–2004)
Latin America & Caribbean	190.0 (+15%)	560.3 (+1%)
North America	206.2 (-9%)	265.6 (+5%)
Europe	290.4 (-3%)	177.1 (-2%)
Middle East and North Africa	92.6 (+0%)	359.6 (-14%)
Sub Saharan Africa	219.3 (+15%)	730.5 (+4%)
Central Asia	38.3 (+0%)	254.7 (+1%)
South Asia	238.2 (-1%)	78.0 (-18%)
East Asia	132.0 (-3%)	505.7 (-2%)
Southeast Asia	112.9 (+15%)	16.9 (+1%)
Oceania	48.8 (-4%)	368.1 (-11%)
World	**1568.6 (+2%)**	**3316.5 (-3%)**

Table 5. Average harvested area and yield for major crops from 2010–2014, and the percentage change from 2000–2004. Data are from the UN Food and Agriculture Organization.

crop type	harvested area (Mha) 2010–2014 (% change from 2000–2004)	yield (t/ha) 2010–2014 (% change from 2000–2004)
wheat	218.8 (+2%)	3.2 (+15%)
maize	176.8 (+26%)	5.3 (+17%)
rice	162.7 (+8%)	4.5 (+14%)
soybean	108.2 (+33%)	2.5 (+10%)

<u>Organic agriculture</u>

Organic agriculture is the most well-known, most wide-spread, and most clearly defined alternative farming system today. Organic agriculture is based on the principles of health, ecology, fairness and care, and its stated goal is not only to provide healthy and nutritious food to consumers but also to alleviate the negative environmental externalities of conventional agriculture (IFOAM, 2006). The organic sector has seen tremendous growth over the last decades, both in area, production, number of producers and the size of its market. The organic market, for example, is currently one of the fastest growing food sectors and has seen double-digit annual growth rates over the last 10 years (Willer & Lernoud, 2017). Organic agricultural area, instead, has grown by 360% since 1999, and 1% of the world's farmland is now managed organically (Willer & Lernoud, 2017). Organic agriculture is expected to continue to grow into the future, not only because the organic sector is currently supply-limited, and consumer demand outstrips supply (Willer & Lernoud, 2017), but also because the growing middle class in countries like India or China are expected to increase the demand for organic food further (Chakrabarti, 2010; Sheng, Shen, Qiao, Yu, & Fan, 2009).

The growth of the organic sector, the expansion of organic agricultural land and the increase in consumption of organic food have come along with an increased role of organic agriculture in contributing to people's well-being (Reganold & Wachter, 2016). But the actual contribution of organic agriculture to people's well-being is often highly debated, sometimes quite uncertain and often characterized by nuanced complexities (Seufert & Ramankutty, 2017). When compared to conventional agriculture, organic agriculture, for example, typically reduces the quantity of provisioning services due to its lower yields (de Ponti, Rijk, & Van Ittersum, 2012; Ponisio et al., 2015; Seufert, Ramankutty, & Foley, 2012) but it might increase the quality of food produced due to slightly higher micro- and macronutrient contents, as well as lower pesticide residues (Barański et al., 2014; Średnicka-Tober et al., 2016). But things are even more complex than this - it is, for example, debated whether the small nutritional differences of organic food are health-relevant, (Smith-Spangler et al., 2012), while the lower pesticide contamination of organic foods are particularly important in developing-country contexts where organic food consumption is currently still low (Seufert & Ramankutty, 2017).

On the other hand, organic agriculture typically enhances regulating services like pollination (Kennedy et al., 2013) and pest control (Crowder, Northfield, Strand, & Snyder, 2010), as well as supporting services like soil formation (Gattinger et al., 2012) on individual farms. But again, the story is more complex than it appears – because of its lower productivity, organic agriculture appears to have lower biodiversity and higher greenhouse gas (GHG) emissions per unit food produced than conventional agriculture (Gabriel, Sait, Kunin, & Benton, 2013; Skinner et al., 2014). Expansion of organic agriculture might require more land area and might thus lead to higher biodiversity loss and higher GHG emissions, if it is not accompanied by simultaneous changes in food demand (Erb et al., 2016).

Organic farming also often has positive impacts on farmers' livelihoods due to the premium prices received, which lead to increased profitability (Crowder & Reganold, 2015). But despite the typically higher profitability, the organic sector is supply-limited and farmers are often reluctant to convert to organic farming. Cultural, technical and market barriers to increased adoption of organic agriculture thus need to be addressed (Padel, 2001). Finally, it has to be emphasized that while organic agriculture is carried out across the world (Willer & Lernoud, 2017), the large majority of scientific studies on organic agriculture have been carried out in the Global North (Seufert & Ramankutty, 2017). The performance of organic agriculture in tropical and sub-tropical low- and middle-income countries is thus characterized by high uncertainties.

Given that organic agriculture is based on a more holistic view of agroecosystems, and the prohibition of synthetic inputs requires organic farmers to work with ecological processes, organic agriculture provides a promising tool to reduce the negative externalities of conventional management. But to increase the potential of organic agriculture to contribute to people's well-being, organic systems need to be intensified sustainably, and barriers for the adoption of organic agriculture need to be addressed. In addition, knowledge gaps on organic agriculture in the Global South need to be closed.

Shifting cultivation

In places where these systems persist – such as the Amazon river basin (Coomes et al., 2017), central Africa and Central and Latin America (Van Vliet et al., 2012) - intensification is constrained by low access to inputs, credits and markets, and multi-functionality of land uses is the best strategy for smallholders (Vliet et al. 2013). In places such as India (Shimrah, 2017) and southeast Brazil (Adams et al., 2013), shifting cultivators adapt to new contexts and diversify their practices, keeping the traditional system as a backup (van Vliet et al., 2013), and possibly buffering the impacts of climate change (Dressler et al., 2017).

Yet, shifting cultivation systems are gradually being replaced in other places (Van Vliet et al., 2012, 2013) caused mainly by increased access to markets, implementation of infrastructure projects, forest conservation policies and demographic changes (Coomes et al., 2017; Chan and Takeda, 2016(Coomes et al., 2017; Chan and Takeda, 2016; Adams et al., 2013; Grogan et al., 2013; Schmook et al., 2013; Van Vliet et al., 2012, 2013)￼These drivers are promoting land use changes, and the intensification of traditional practices, greater use of external inputs and replacement of traditional agricultural plots with more profitable, permanent practices ￼. Vliet et al., 2012, 2013)￼Positive outcomes of these changes are improved household livelihoods and income increase, and a reduction in forest conversion (Dressler et al., 2017; Adams et al., 2013; Grogan et al., 2013; Vliet et al., 2013). However, decrease in shifting cultivation area (Van Vliet et al., 2012)￼ has caused a reduction in crop productivity, soil fertility (Dressler et al., 2017; Schneibel et al., 2017Delang et al., 2016; Jakovac et al., 2016; Van Vliet et al., 2012) and agrobiodiversity (Van Vliet et al., 2012Delang et al., 2016; Pérez-García and del Castillo, 2016), as well as ecosystem services, carbon stocks and forest landscape complexity (Van Vliet et al., 2012Heinimann et al., 2017; Fantini et al., 2017; Heinimann et al., 2017; Wood et al., 2016; Adams et al., 2013). In addition, conflicts over land and farmers' out migration are observed , along with reduction in food security and resilience .

By and large, shifting cultivation land use area is expected to reduce significantly worldwide in the next decades, and to be gone by the end of this century (Heinimann et al. 2017). Due to local policies and economic growth, Asia is expected to be the first to face shifting cultivation land disappearance, followed by the Americas and Africa. Implementation of local policies sensitive to shifting cultivator's needs and the environmental and sociocultural values of these humane environment systems (Fantini et al., 2017; Heinimann et al., 2017; Mandal and Shankar Raman, 2016; Zaehringer et al., 2016), such as preserving forested areas as an integrative part of farmers' livelihoods and wellbeing (Mandal and Shankar Raman, 2016; Mukul et al., 2016), could help to maintain their contribution to the good quality of life of smallholders in forested areas.

Figure 4 (Heinimann et al., 2017)

Figure 4. Estimation of landscapes showing signs of shifting cultivation around 2010 between 30oS to 30oN. Based on visual inspection of annual global deforestation data [8] from 2000 to 2014 and very high-resolution satellite imagery. Areas in which shifting cultivation can be assumed to have never existed or disappeared decades ago have been excluded from the analysis (dark gray). This figure was elaborated by the first author (Heinimann et al., 2017) using ArcGIS 10.4.

Table 6. List of the main pastoral areas and associated animal species across the world. The last columns document evolution trends (FAO 2001).

Zone	**Main species**	**Status**
Sub-Saharan Africa	Cattle, camels, sheep, goats	Reducing because of advancing agriculture
Europe	Small ruminants	Declining everywhere because of enclosure and advancing agriculture
North Africa	Small ruminants	Reducing because of advancing agriculture
Near East and South- Central Asia	Small ruminants	Declining locally because of enclosure and advancing agriculture
India	Camels, cattle, buffaloes, sheep, goats, ducks	Declining because of advancing agriculture, but peri-urban livestock production is expanding
Central Asia	Yak, camels, horses, sheep, goats	Expanding following decollectivization
Circumpolar zone	Reindeer	Expanding following decollectivization in Siberia, but under pressure in Scandinavia

North America	Sheep, cattle	Declining because of increased enclosure of land and alternative economic opportunities
Central America	Sheep, cattle	Declining because of increased enclosure of land and alternative economic opportunities
Andes	Llamas, alpaca, sheep	Contracting llama production because of expansion of road systems and European-model livestock production, but increased alpaca wool production
South American	Cattle, sheep	Expanding where forests are converted to savannah, lowlands but probably static elsewhere

Wild food and meat

A wide variety of game (38 species), mushrooms (27 species) and vascular plants (81 species) is collected and consumed throughout the EU. Income, age, gender, possibilities for collecting, and cultural factors explain the importance of wild food. While the economic and nutritional values of wild food comprise a few thousands of the GDP or total consumption, over 100 million EU citizens consume wild food. Collecting wild food is an appreciated recreational activity; collecting and consuming wild food provide important cultural ecosystem services, including recreation and sense of place.

Across the humid tropics, wild meat is being consumed on a massive scale. Humans have been hunting wildlife in tropical forests for 100 000 years or more, but consumption has greatly increased over the past few decades. Recent estimates of the annual wild meat harvest are 23 500 tonnes in Sarawak (Bennet 2002), 67 000– 164 000 tonnes in the Brazilian Amazon (Robinson & Redford 1991, Peres 2000), and 1 million–3.4 million tonnes in Central Africa (Wilkie & Carpenter 1999, Fa et al. 2001). Productivity of tropical forests for wild meat is at least an order of magnitude less than that in more open habitats, such as savannahs. If people depend solely on wild meat for their protein, human population densities > one person km2 are unsustainable in tropical forests (Robinson & Bennet 2000). Hunting rates are already unsustainably high across large swathes of the tropics, averaging six times the maximum sustainable rate in Central Africa, for example (Bennet 2000). Consumption is both by rural communities and by urban consumers, who are often at the end of supply chains that are hundreds of kilometers long (Fa 2000, Millner-Gulland & Clayton 2002).

Marine

Naturally reproducing fish populations have been harvested from oceans and inland waterbodies for millennia to provide food for humans, but large increases in fishing effort over the past century, coupled with anthropogenic pressures including habitat degradation and pollution have placed increasing pressure on wild fish stocks (Pauly & Zeller, 2016). Total (global) reported marine fish landings have remained relatively stable since the late 1980s, with a slight increase from 2010-2014. Supply of fish for animal feed has remained fairly stable at around 20 million tons/yr since 1970. This equates to 27% of reconstructed global marine fisheries landings between 1950 and 2010 estimated to have been for purposes other than direct human consumption (Cashion et al. 2017). Global capture fisheries production peaked in the mid-1990s as a result, and has since begun to decline by roughly 1 million metric tons per year (Pauly & Zeller, 2016). Industrial fishing overexploitation is the primary cause of these declines. Production of fish as food for humans is growing at a rate of 3.2% per annum (WOA 2016). This is wild caught fish as well as farmed fish (aquaculture), from the ocean, estuaries, rivers and lakes. In addition, fish is also used to make feed for domestic animals and for cultured aquatic resources (aquaculture). Overall, close to 90% of World fish catches are of marine origin rather than from inland fisheries (FAO 2018). Global total capture fishery production in 2016 was 90.9 million tonnes; 793 million tonnes from marine waters, and 11.6 million tonnes from inland waters (FAO 2018). However, reconstructed catch series that account for illegal, unregulated and unreported catches (IUU) estimate peak catches up to 130 million tons in the late 1990s, with strong declines since as a result of, or following management response to overfishing (Pauly and Zeller 2016).

There will be enormous impacts of climate change on fish catch. Climate change will increase sea temperature and drive fish populations from the equator to the poles. Ocean warming and shifts in net primary production are likely to drive remaining fish and shellfish species from low to high latitudes, potentially reducing catch globally by more than 6% and by as much as 30% in some regions (such as the tropics) by 2050 relative to recent decades (Cheung et al. 2016). Ocean warming and associated declines in oxygen content are projected to reduce the average biomass of fish communities by around 20% during this period (Cheung et al. 2013). Coral reefs, foundational ecosystems for many tropical subsistence and artisanal fisheries, will be heavily degraded by warming and bleaching.

In terms of nutritional impact, we expect there to be three typologies of countries in how they would be affected from a local collapse in their fisheries. There will be the wealthy unaffected nations like the US, Japan, New Zealand, etc. where a local collapse in the fisheries will lead to slight price shifts or species shifts in the markets, but those who were eating fish before will continue to eat fish, and those who were not eating fish before will continue to not eat fish. There will also be countries where undernutrition will increase- places like Madagascar, Gabon, Suriname, etc. These are places where a local collapse of the fisheries will increase a reliance on tubers or vegetarian foods driving increases in micronutrient deficiencies. Finally, there will be countries where a local collapse of the fisheries will accelerate the nutrition transition., e.g in Indonesia, Brazil, Mexico, and the islands of the South Pacific. Reductions in fisheries causes a decline in traditional diets and increases in western diets, fast foods, processed foods, and a rise in metabolic disease.

To solve this predicted future socio-ecological crisis, efforts will need to be coordinated across economic markets, ecological management, and technological innovation. Aquaculture will certainly help to stabilize food security but it will not be a silver bullet (Golden et al. 2017). Aquaculture production outpaced wild fish catch production in 2014 (Kobayashi et al. 2015). However, aquaculture is not currently oriented to support the nutrition of vulnerable populations in the developing world (Golden et al. 2017). Yet, there is enormous potential for policy reforms to help direct benefits of aquaculture to the nutritionally vulnerable (Thilsted et al. 2016).

We also need to consider improvements in fisheries management to deliver seafood to local people in the form of nature's contribution to people. Currently, 60% of fisheries are either overexploited or fully collapsed (Froese et al. 2012). An additional 35% are fully exploited (Froese et al. 2012). In 1974, 90% of the World's assessed fish stocks were classified as being at biologically sustainable levels, whereas in 2015, this fraction had dropped to 66.9% (FAO 2018). Although there are indications that several fisheries are stabilizing (e.g. Worm et al. 2009), there are strong indications that, even using less conservative methods than FAO's, over 40% of assessed fish stocks are over-exploited or in a collapsed state (Anderson et al. 2012). Extending this assessment to non-assessed, fished stocks on the premise that catch is a reasonable estimator of stock status, yielded similar results (Kleisner et al. 2013). This implies that there is little scope for enhancing wild capture fisheries production unless stock rebuilding is successful. However, even then the processes behind stock rebuilding still require extensive further scientific and management research (WOA chap 10). Therefore, we need to reframe fisheries management around providing nutritional benefits, to allow fisheries to recover, and to deliver seafood to local populations. This then reframes environmental conservation as a key strategy in nutritional interventions.

Supply of fish for human consumption has more than doubled since 1995, largely due to aquaculture. The contribution of aquaculture to fish supply for human consumption increased from 7% in 1974 to 44% and 47% in 2014 and 2016 respectively (FAO 2016; FAO 2018). This increase is largely attributable to China. However, 43% and 59% of total World aquaculture production including and excluding aquatic plants, respectively, is of freshwater (inland) finfish (FAO 2016: Table 9). Concomitantly, the proportion of fish production used by humans for purposes excluding food (75% of this fraction is converted to fishmeal and oil for animal feed, but other uses include fertilizers, the aquarium trade, pharmaceutical/medicinal purposes, etc.) has steadily declined; from around one third to about one fifth of total capture fishery harvest in 2012 (FAO 2014a). It is estimated that by 2016 world food fish aquaculture production had risen to 80 million tons, non-food aquaculture products totaled 37 900 tons and production of farmed aquatic plants (including mostly seaweeds) being estimated at 30.1 million tons (FAO, 2018). Aquaculture of both aquatic animals and aquatic plants (mainly seaweeds) has steadily increased

It is important to note that around 64% of fishmeal and fish oil used to feed aquacultured species is obtained directly from fish captured for this purpose as opposed to from byproducts of fisheries. Hence discussion has ensued around direct versus indirect consumption (for land farming and aquaculture) of small pelagic fish (e.g. HLPE 2014; Metian 2009). Close to 70% of the farmed finfish production is dependent on artificial feeding rather than on the natural environment for sustenance (FAO 2014; World Ocean Assessment (WOA), chap 12). This has food-web and socio-economic implications; for example removal from the natural ecosystem of forage fish to support farming/culturing of animals (marine and livestock) has implications for predatory fish relying on these fish as prey, and the fisheries that target these predatory fish. In fact, it has been estimated that 90% of the fish not directly used for human consumption is food-grade fish (Cashion et al. 2017).Further, aquaculture operations have a range of environmental impacts that need to be taken into consideration (WOA chap 12).

<u>*Summary of NCP trends:*</u>

- ***Trend*** (& why): Crop and livestock production are increasing in general, both through increases in area and productivity, mostly via expansion of industrial agriculture. Other forms of food production (shifting cultivation, pastoralism, etc.) are decreasing. Wild caught fish production is stabilizing or decreasing (see above) whereas aquaculture production is on the increase to meet the increasing demand of the increasing human population.
- ***Spatial variance*** (& why): Land in agriculture has decreased in temperate regions, agricultural land increased by 6 million hectares per year across subtropical and tropical regions. The largest increases in cropland occurred in Latin America and the Caribbean, Sub Saharan Africa, and Southeast Asia, regions which saw a 15% increase in cropland between 2000–2004 and 2010–2014. Harvested area in major crops has also increased over this period, most substantially for maize and soybean, with growth concentrated in Africa, South America, and Asia. Overall trend in marine food is generally consistent but there is spatial variance in magnitude of the changes across the world - depends on the productivity of the region and on fisheries management implemented and its effectiveness.
- ***Degree of certainty*** (& why): It is certain the trends and spatial variance in food production from industrial agriculture, but it is somewhat uncertain the changes in other forms of food production, specially wild food collection. High uncertainty in exact values attributed to marine food production, for example in the marine environment this is associated with IUU (illegal, unregulated and unreported catches).

12.3.5.2. By Units of Analysis

Unit of Analysis	Direction of arrow	Rationale/ justification for why you think this trend is happening
12. Aquaculture areas LUC? Management: More intensive	Up	Aquaculture production is increasing (see text above and FAO (2018) report
14. Shelf ecosystems (neritic and intertidal zone, estuaries, mangroves) LUC ?	down	Catches declining globally as a result of worsening stock status and/or management interventions (Pauly and Zeller 2016)
15. Open ocean pelagic systems LUC ?	down	Catches declining globally as a result of worsening stock status and/or management interventions (Pauly and Zeller 2016)
16. Deep-sea LUC ?	down	Catches declining globally as a result of worsening stock status and/or management interventions (Pauly and Zeller 2016)

12.4. Impacts on good quality of life

12.4.1. Different types of value

12.4.1.1. What is the NCP contribution

Terrestrial - pastoralism

Food from pastoralism and agropastoralism is making a key contribution to well-being at the global level through different ways:

Direct contribution to subsistence

Pastoral production systems provide direct subsistence (either through food production or income generation) to a large number of people across the globe. Estimates vary widely depending on the definition of pastoralism they use (Krätli et al. 2013). De Haan et al. estimate that in 1997 at least 20 million households depended solely on pastoral livestock production for subsistence, while around 200 million smallholder farmers depended on livestock raising as a key source of income (De Haan et al. 1997).

Focusing only on drylands, Rass estimates that there are about 120 million pastoralists and agropastoralists worldwide, 50 million of which live in Sub-Saharan Africa, 31 millions in West Asia and Northern Africa, 25 millions in Central Asia, 10 million in South Asia and 5 million in Central and South America (Rass 2006). These estimates are based on (Thornton et al. 2002).

Within sub-Saharan Africa, highest pastoralist numbers are found in Sudan and Somalia (7 million each) and in Ethiopia (4 million) (Rass 2006). Pastoralism also represent a key contribution to national economies and livelihoods: in Sudan for example, 90% of the national herd is in pastoral systems and about 98% of which supplied the domestic market (Behnke and Osman 2012). In Burkina Faso, 70% of the cattle population is herded by the Fulani pastoralists (IIED and SOS Sahel 2009). The traditional livestock sector in Tanzania produces 70% of the country's milk, which was 770 million liters in 2006 (United Republic of Tanzania 2006).

An efficient livestock production system

A key feature of pastoral systems is that the mobility enable them to make an efficient use of harsh environments not suitable for sedentary agricultural production.

It has been shown that in drylands nomadic and seminomadic pastoralism is more productive than ranching systems, be it compared per unit of land (Breman and Wit 1983, Scoones 1994) or across a set of indicators such as calf mortality (Wilson and Clarke 1976, cited in IIED and SOS Sahel 2009). A study comparing sedentary, transhumant and nomadic cattle undertaken in Niger has shown the same results in 1995 (De Verdière 1995). [NB: many other references are available about this aspect]

Thus, pastoralism makes a key contribution to global well-being through producing food in an efficient way from environments that do not suit other food production systems.

Contribution to the livelihood of poor peoples

Pastoralism is a key subsistence strategy for poor peoples, as estimates show that about one third of the 120 million pastoralists worldwide are extremely poor (Thornton et al. 2002, Rass 2006)

Contributions of pastoralism and agropastoralism to food security: four dimensions

Pastoralism – sedentary, transhumant or nomad - contribute to good quality of life globally and across regions by ensuring food security across its four dimensions: availability, access, stability and utilization.

First, it provides food at the local scale, by making meat, milk and other food products from livestock materially available for local people. Even when they rely highly on markets for selling livestock products, pastoralists usually sell or barter part of their production with farmers and villagers along their migration routes, thus making food available to these local people.

Second, as many pastoralists are smallholders, raising livestock is a way to increase household incomes through the direct sale of products, and thus it contributes to improving nutritional status of the rural poors. Pastoralism contributes in complex ways to food availability and access.

Third, livestock contributes to stability in food provision because it can be used as an asset to buffer income gaps or in time of crisis. Animals can be sold and the money used for food supply when households face a food crisis.

Fourth, pastoralism contribute to utilization because animal products are of high nutritious value for humans. In meat and dairy products, the bioavailability of trace elements such as iron and zinc is higher than in vegetables and they content high-quality proteins and micronutrients. Livestock products are an easy and affordable source of high-quality food for consumers (FAO 2009: 39-40).

Pastoralists are the gene-keepers of domestic breeds

A key contribution of pastoralists to global food and well-being is the selection, over centuries, of local breeds of domestic animals that are specifically adapted to the environments they evolve in (IIED and SOS Sahel 2009). For example in India several breeds of sheep, cattle, buffalo, and camel have been "created" by pastoralists, in a complex set of interactions between social systems, traditional knowledge, ecosystems and domestic animals (Köhler-Rollefson and LIFE network 2007). These breeds are key in these pastoral systems as they enable the functioning of the whole system in specific environmental conditions and they ensure animal genetic diversity. The survival of these breeds depends on the maintenance of the ecological and social settings they are embedded in (Köhler-Rollefson and LIFE network 2007). Initiatives are being taken by international organizations such as IUCN or the League for Pastoral Peoples to better protect local breeds and the rights of the pastoralists who selected them and breed them .

Food products from pastoralism support livelihoods outside of pastoralism
Pastoralist systems also contribute to global well-being through providing work for tens of thousand people involved in the processing and the trade of pastoral food products (Gertel and Le Heron 2011, Krätli et al. 2013).

*Pastoral systems contribute to other food production system*s
Pastoralists make important contributions to farming systems through manuring and provision of draft animals (IUCN WISP 2014).

Trends in the impacts of food from pastoralism on global well-being
Pastoral food production systems, despite being highly adaptive, face a number of changes worldwide. The changes taking place are due to a variety of factors and affect the pastoralists in various ways.

Land use changes: impacts on mobility and accessibility of pastures
Pastoralists rely on mobility to deal with variations in natural resources availability across time and space. However, their ability to move is reducing in several regions of the world due to land use changes and landscape fragmentation. Processes such as infrastructure building and fencing impede mobility, and thus reduce the ability of pastoralists to take advantage of available natural resources as well as to respond in case of critical event. Reduced mobility for pastoralists translate into an increased vulnerability (Dong et al. 2011)

Alienation of pastoral resources to conservation or irrigation schemes, or to biofuel production (“land grabbing”) is another key driver of change among pastoralist systems, leading to livelihood changes: pastoralists tend to diversify they agricultural and non-agricultural activities to compensate lower return of pastoral activities (Galaty 2013, Krätli et al. 2013, Davis et al. 2014).

Vulnerability to climate change
Most of the pastoral systems are found in drylands, areas that are more likely to be affected by climate change. While pastoral systems are also likely to be affected by climate change, it has been shown that their vulnerability to climate change is mostly driven by non-climatic factors, such as land use changes, accessibility of pastoral resources, national policies and institutional settings (Nori and Davies 2007, Nori et al. 2008)
Identifying clear evolution trends for pastoral systems is uneasy, as these systems constitute a complex landscape in which multiple components are involved.
In a very general perspective, we can observe that in Africa, Middle East, Northern Europe and Siberia, pastoralists’ ability to move has reduced during the last decades, mostly due to land use changes. These processes led to diversification of pastoral livelihoods, intensification in some cases, and reduced mobility or sedentarization.
In the former soviet republics from Central Asia, the changes that followed decollectivisation of pastoral production have led to an expansion of pastoralism (FAO 2001).

Marine - fish
Fish are a large, but underappreciated, component of the global food system (Béné et al, 2015). Although commonly thought of as source of protein, fish’s most important contribution to diets is as a rich source of vitamins, minerals and fatty acids, essential to human health and development (Golden et al. 2016, Bogard et al, 2017). The regions in which fish makes the largest contribution to human diets (much of Asia and parts of Africa) are among those where the highest levels of undernutrition are found (Hall et al., 2013). An estimated 845 million people are ‘seafood dependent’, most of them living in countries in these regions (Golden et al, 2016).

Naturally reproducing fish populations have been harvested from oceans and inland waterbodies for millennia to provide food for humans, but large increases in fishing effort over the past century, coupled with anthropogenic pressures including habitat degradation and pollution have placed increasing pressure on wild fish stocks (Pauly & Zeller, 2016). Global capture fisheries production peaked in the mid-1990s as a result, and has since begun to decline by roughly 1 million metric tons per year (Pauly & Zeller, 2016). Industrial fishing overexploitation is the primary cause of these declines.

There will be enormous impacts of climate change on fish catch. Climate change will increase sea temperature and drive fish populations from the equator to the poles. Ocean warming and shifts in net primary production are likely to drive remaining fish and shellfish species from low to high latitudes, potentially reducing catch globally by more than 6% and by as much as 30% in some regions (such as the tropics) by 2050 relative to recent decades (Cheung et al. 2016). Ocean warming and associated declines in oxygen content are projected to reduce the average biomass of fish communities by around 20% during this period (Cheung et al. 2013). Coral reefs, foundational ecosystems for many tropical subsistence and artisanal fisheries, will be heavily degraded by warming and bleaching.

In terms of nutritional impact, we expect there to be three typologies of countries in how they would be affected from a local collapse in their fisheries. There will be the wealthy unaffected nations like the US, Japan, New Zealand, etc. where a local collapse in the fisheries will lead to slight price shifts or species shifts in the markets, but those who were eating fish before will continue to eat fish, and those who were not eating fish before will continue to not eat fish. There will also be countries where undernutrition will increase- places like Madagascar, Gabon, Suriname, etc. These are places where a local collapse of the fisheries will increase a reliance on tubers or vegetarian foods driving increases in micronutrient deficiencies. Finally, there will be countries where a local collapse of the fisheries will accelerate the nutrition transition. Countries like Indonesia, Brazil, Mexico, islands of the South Pacific. Reductions in fisheries causes a decline in traditional diets and increases in western diets, fast foods, processed foods, and a rise in metabolic disease.

To solve this predicted future socio-ecological crisis, efforts will need to be coordinated across economic markets, ecological management, and technological innovation. Aquaculture will certainly help to stabilize food security but it will not be a silver bullet (Golden et al. 2017). Aquaculture production outpaced wild fish catch production in 2014 (Kobayashi et al. 2015). However, aquaculture is not currently oriented to support the nutrition of vulnerable populations in the developing world (Golden et al. 2017). Yet, there is enormous potential for policy reforms to help direct benefits of aquaculture to the nutritionally vulnerable (Thilsted et al. 2016).

We also need to consider improvements in fisheries management to deliver seafood to local people in the form of nature’s contribution to people. Currently, 60% of fisheries are either overexploited or fully collapsed (Froese et al. 2012). An additional 35% are fully exploited (Froese et al. 2012). We need to reframe fisheries management around providing nutritional benefits, to allow fisheries to recover, and to deliver seafood to local populations. This then reframes environmental conservation as a key strategy in nutritional interventions.

12.4.1.2. How do we measure that value/contribution?

- Monetary value of harvest
- Number of jobs dependent on food production sector
- Nutritional value of harvest

- Prevalence of food-related cultural activities

12.4.1.3. Substitutability

Substitutability for final NCP:
No substitute for final product
Individual food source could be substituted, either by type or by location of production
Food with cultural meaning is less substitutable.

Substitutability in process of food/feed production:
Individual inputs to agricultural production (e.g. fertilizer) can be substituted

Marine
Ocean-based sources of income, jobs, and protein may be substituted by land-based equivalents in contexts where these substitutes are accessible and affordable.
Ocean-based sources of food-related recreational activities may to some extent be substituted by land-based activities such as “hunting” or farming.

Fish meal replacements are being considered - for example, insect-based industries have been initiated to produce insect-based meal as substitutes for meal based on fish like anchovy/sardine.

12.4.1.4. Status and Trends in impact (value)

Marine
Indicators of the benefits of the food supply to people:
A useful example here is Hattam et al. (2015) who used the following indicators in a North Sea case study – these can be reported separately for farmed versus capture fisheries - Nutrition (grams protein/year/capita or per household); Fisheries revenues and contribution to Gross Value Added (GVA) –Monetary value (e.g., in £, $ or Euros); Employment in fisheries Number of jobs; Potential catch loss in the absence of stock rebuilding initiatives (Srinivason et al. 2010 – shows increase across most regions/systems); ex-vessel revenue (Sumaila et al. 2007).

12.4.2. Indicators of NCP impact

12.4.2.1. Indicators by value

Value type	Indicator/ Proxy	Rationale/ justification for why we this indicator/ proxy was selected	Data set	Scale of Measure – space	Scale of measure - time
Cultivated	Value of production	FAO			
Wild	Value of catch				
Cultivated	Nutritional output (calories, nutrients)	FAO			
Subsistence cultivated	Farm size distribution	Maybe helps us get at subsistence farmers? Samberg et al in Environmental Research Letters			
Food source	Nutrition derived from fish	*Hattam et al. 2015*	?	?	?
Economic value	Fisheries revenues; Gross Value Added	*Hattam et al. 2015;* *No global database exists for costs, so revenues (ex-*	Srinivason et al. 2010 (Potential catch loss in the	Global	1950s onwards

	(GVA); Potential catch loss; *Production of fish meal and fish oil use in aquaculture/animal feeds*	*vessel) Is likely the best we can do. This also does not reflect profits/revenues of people up the supply chain (processors, fish markets)*	absence of stock rebuilding initaitives) Sumaila et al. 2007 (ex-vessel landed value) *The Marine Ingredients Organisation IFFO: http://www.iffo.net/*	 Global (maps) Global by taxa fished	 1950s onwards 1976 onwards
Employment	No. of jobs			National/local only	variable

12.5. Summary

12.5.1. Status

Globally, production of food is high and increasing. For agricultural crops, both harvested area and yields have increased, and meat and milk production have both increased over the past 50 years (Alexandratos and Bruinsma 2012). However, nature's contribution to food production is declining. Currently, ~60% of major cropland areas and ~52 % of global rangeland is facing land degradation. Global fish catches increased by around 50% in the last 50 years, and cultured (farmed) fish production escalated from insignificant fractions of wild catch to comprise around 47% of total wild and farmed seafood production in 2016 (FAO 2018). Catches appear to be stabilizing in recent decades (Worm et al. 2009; FAO 2018) but demand for fish resources is increasing given increasing human populations, likely with reduced benefits in terms of livelihood per fisher. This is a reflection of the state of our World's fish stocks – there is little scope for expanding fisheries into the future (FAO 2018). In the last ten years, wild fish catch declined by 10% whereas farmed fish/seafood increased by 20%. 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 due to overfishing (Srinivasan et al. 2010) and 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 (Cheug et al. 2016). Food and feed production have increased in all regions, but with different magnitude. For example, meat and milk production have increased ten- and seven-fold in Asia, while only 81% and 8% in Europe. 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). 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(Khoury et al. 2014; Herrero et al. 2017). 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 (Murray, Willett). Unhealthy foods are a major driver of climate change, land expansion, and loss of biodiversity (Tilman and Clark 2014). Shifts to recommended healthy diets would reduce foods impacts on several other NCPs, notably climate, water quality, and habitat for biodiversity (Springmann et al. 2018).

	Potential Nature's Contributions	**Output of the joint production**	**Impact on good quality of life**

Indicator	Arable Land Remaining Fish Catch Potential	$Food_{quant}$: kcal capita^{-1} $Food_{qual}$: Dietary Diversity	Hunger Malnutrition
Trend	ALR: -1 FS: -2	$Food_{quant}$: +2 $Food_{qual}$: -1	Hunger: 0 Malnutrition: -2
Spatial variance 3 = opposite trends in different regions 2 = same directional trends in different regions but of contrasting magnitude 1 = similar trends all over the world	ALR: 2 FCP: 2	$Food_{quant}$: 2 $Food_{qual}$: 2	Hunger: 3 Malnutrition: 3
Variance across user groups 3 = opposite trends for different groups 2 = same directional trends for different groups but contrasting magnitudes 1 = similar trends for all social groups	NA	NA	Hunger: 3 Malnutrition: 3
Degree of certainty 4 = **Well established**: Robust quantity and quality of evidence & High level of agreement 3 = **Established but incomplete**: Low quantity and quality of evidence & High level of agreement 2 = **Unresolved**: Robust quantity and quality of evidence & Low level of agreement 1 = **Inconclusive**: Low quantity and quality of evidence & Low level of agreement	ALR: 4 FCP: 2	$Food_{quant}$: 4 $Food_{qual}$: 4	Hunger: 4 Malnutrition: 4
Two to five most important papers supporting the reported trend			

Terrestrial

There has been a large increase in food output as well as a change in intensity of food production/harvest versus farmed/fished area. This partially implies that our natural support systems are doing more to provide food/feed, although it also means that in some places high intensity production is degrading these support systems (e.g. soils).

Marine

There is an increasing demand for food to sustain the World's increasing human population. This is putting stress on both terrestrial and aquatic ecosystems. For example, in the case ocean biomes, catches of wild-caught fish have been on a steady increase until recent years, when a levelling off of landed catches has been recorded. This is a reflection of the state of our World's fish stocks – there is little scope for expanding fisheries into the future. The response to this has been a marked increase in the quantity of marine resources that are now “farmed” through the growing aquaculture industry. However, aquaculture activities can pose environmental threats to ecosystems and these should be carefully contained and considered as we develop fish as a growing food and feed supply.

Tradeoffs: aquaculture can affect the ability of e.g. mangroves or offshore fisheries to provide important services; Barbier (2012) uses a case study in Thailand to illustrate that aquaculture, being detrimental to mangroves (conversion of mangroves to shrimp farms – also mentioned in Tinch and Mathieu 2011 (authors of the UNEP report)), diminishes the role of mangroves in providing nursery and breeding areas for fish that support important offshore fisheries (this is an ecosystem service termed “Lifecycle Maintenance” - see Bőhnke-Henrichs et al. 2013).

12.6. References

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12.7. Search methodology

1. fish catch marine food supply production -freshwater -lake –river

17400 results if anywhere in article! So I refined:

2. Catch marine global

9 articles over all years if in title of article, of these 5 were very useful.

Thus, I decided to use these 5 to augment the detailed FAO reports and the recently published, very comprehensive review The World Ocean Assessment. In addition, Laura and I added key papers with which we were familiar from our marine fisheries and ecosystem research and which were "lost" in the global searches, or very new.

World Ocean Assessment (WMO) - see Chap 1 pages 19 and 20 for overview of fisheries and aquaculture – productive ecosystems ensure good supply of these NBPs.
WOA is a useful source for detailed information – Chapter 10 (general background – "The Oceans as a Source of Food"), Chapter 11 (Capture Fisheries in detail), Chapter 12 (Aquaculture in detail).

Databases:
FAO fisheries and Aquaculture records: http://www.fao.org/fisheries/en/;
Sea Around Us: http://www.seaaroundus.org/;
Census of Marine Life (for Biodiversity patterns and spatial distributions of the ecosystems supporting the supply of fish); data and references within: Melnychuk, M.C., Peterson, E., Elliott, M. & Hilborn, R. (2016). Fisheries management impacts on target species status. Proc. Natl. Acad. Sci., 114, 201609915; for ex-vessel revenue, Sumalia et al. (2007) - there are global maps within that paper.

13. NCP 13 - Materials and assistance

Primary Author: Uttam Babu Shrestha

13.1. IPBES Definition:

Production of materials derived from organisms in cultivated or wild ecosystems, for construction, clothing, printing, ornamental purposes (e.g. wood, fibres, waxes, paper, resins, dyes, pearls, shells, coral branches).

Direct use of living organisms for decoration (i.e. ornamental plants, birds, fish in households and public spaces), company (i.e. pets), transport, and labor (including herding, searching, guidance, guarding).

13.2. Why is it important?

Materials for shelter, clothing, and construction provided by nature are the basis for material wellbeing of humans and have non-material meaning as well. This category of NCP includes both consumptive (i.e. fiber, woods) and non-consumptive (i.e. pets, ornamental plants) materials. There are different types of materials that are used directly for subsistence (i.e. local wood collection, fodder/grass collection) to industrial raw materials (roundwood, pulps, resins, latex) that require a heavy industrial processing. Materials can be divided in to two broader categories: 1) Dead materials and alive materials. A wide variety of dead materials provided by nature can be broadly divided into three groups based on their source of origin: a) materials derived from forest ecosystems, b) materials derived agro-ecosystems, and c) materials derived from aquatic ecosystems. Companion organisms unlike other dead materials derived from (forests, agro and aquatic systems) are living plants and animals directly used for decoration, company, and assistance are discussed separately.

a) Materials derived from forest ecosystems

Wide varieties of materials are derived from forest (natural and plantation) ecosystems. Wood, bamboos and rattans, gums, resins, latexes, cork, and bark are the major materials derived from forests. Currently, most of the materials such as timber, raw materials for panel production, pulpwood and paper production as well as gum arabic, rubber and cork are produced from the productive tree plantations (Lambrechts et al, 2009).

Wood is primarily used as a raw material for construction, furniture and paper and pulp (Agrawal, 2013). The estimated global trade of forest-based products including timber and non-timber forest products (NTFPs) is about 327 billion (FAO, 2007). The international trade in wood-based products is worth more than US$ 250 billion per year (Hoare, 2015).

Bamboos and rattans are used as a substitute of woods and used as raw materials for construction (housing, fodder), woven products (handicrafts, mats), furniture, industrialized bamboo products (paper, panels, boards, veneer, flooring, roofing). The international trade of bamboos and rattans in 2012 was about US $ 2.5 billion (INBAR, 2012).

Biochemical and biodynamic compounds (Gums, resins, latexes, oil, waxes, tannins, dyes, hormones etc). **Gums and resins** are used in food, pharmaceutical products and several other technical applications (Coppen, 1995) whereas **Latex** is used in the production of tyres, health instruments, toys, balloons, gloves and condoms (Sorrenti, 2016). Latex is the milky substance secreted by the lactiferous channels of many plants. The major commercial source of natural latex is extracted by tapping Hevea brasiliensis (Euphorbiaceae family), and Ficus elastica (Indian Rubber) known as the rubber tree. True gums are carbohydrate polymers that are formed in plants, usually Das a result of a process called gummosis (Sorrenti, 2016). Natural resins are polymeric materials produced through secretions from some types of plants, particularly conifers, or other tropical plants that exude them when the bark is somehow incised (Sorrenti, 2016). Global sales from natural rubber exports by 15 top exporter country in 2016 amounted to US$12 billion (The World Factbook, 2017).

Cork is produced from the thick outer bark of cork oak trees (Quercus suber) (Sorrenti, 2016). Cork is used mainly for stoppers, but also for flooring and wall coverage, heels and soles for shoes, textile fibre and other purposes (APCOR, 2016)

Bark is used as a raw material for plaiting, dyeing and tanning, and decoration. It does not have a significant global use and trade except in India and Japan.

b) Materials derived from agro-ecosystems

Natural fibres, which provide clothing for humanity, are primarily derived from agro-ecosystems. Globally, natural fibres are produced from a wide variety of crops such as cotton, flax, hemp, jute, sisal, agave, coir, and manila and are also derived from domestic and wild animals as well as insects. For example, silk is produced by silkworm fed the leaves of the mulberry tree.

- **Cotton** accounts for more than 40% of total fibre production in the world. It is the world's most important non-food agricultural commodity with an estimated global market of US $ 77 billion in 2014/2015 (Rasche et al., 2016; Cotton Australia, 2016).
- **Flax** is the major source of cloth fiber (linen). Flax fiber is a raw material used in the high-quality paper industry for the use of printed banknotes.
- **Jute** is used primarily for coarse fabrics used in burlap, twine, and insulation. Likewise, the fiber derived from **Sisal** is used for cordage, such as binding twine for hay bales.
- The fiber derived from **Hemp** is used to produce various kinds of cordage, paper, cloth, oakum, and other products.
- **Silk** is mainly used for textiles. Skins, fur and wools, shells, and hairs derived from domestic animals are used for clothing, textiles and making accessories such as footwear, shawls, and wallets. The wool of the Tibetan antelope (Chiru pantholops hodgsonii) known as shahtoosh or 'soft gold' is used to make very expensive luxurious shawls that costs more than the price of gold.

c) Materials derived from aquatic ecosystems

Materials such as **coral, pearls, shell** for jewelry, curio, handicraft, fashion as well as cultural and religious ceremonies are sourced from aquatic (marine and freshwater) ecosystems. The trade of ornamental marine species including corals, other invertebrates mostly mollusks, shrimps, anemones and fishes is estimated around US$ 200-300 million annually (Wabnitz et al., 2003). The most recent estimated value of aquatic-ornamental industry (AOI) that includes the trade of aquatic organisms for home and public aquariums, water gardens along with associated equipment and accessories is around 15 billion US dollars (Prang G, 2008; Whittington and Chong 2007; Moorhead and Zeng, 2010).

d) Companion organisms

The collection of wild animals for human entertainment and companionship has been a part of human culture since prehistory (Driscoll & Macdonald, 2010; Bush et al., 2014). According to the fossil evidence, an association between human beings and animals dating back at least half a million years (O'haire, 2010). Numerous living organisms are directly used for decoration, company, and assistance such as transport, and labor (including herding, searching, guidance, guarding) by humans. Traditional societies rely on animal power for food production and other production task. Animals are used for ploughing (oxen, buffalo) or logging (yaks, elephants), riding (ponies, horses, donkeys, elephants, yaks, camels), transportation (reindeer are used in the Arctic and sub-Arctic Nordic countries and Siberia for transportation), hunting (hounds and other dogs are used to kill and fetch prey, domestic cats are used for hunting small rodents and birds, cormorants—an aquatic bird is used to catch fish in China). Dogs are used as sniffing animals by security personals and used as a herding to assist shepherd by many communities in the Himalayas to the Australia and New Zeeland. In ancient societies, horses and elephants were heavily used in war and military purposes. Homing pigeon is used to carry messages as messenger pigeons. Exotic animals are popular pets in many parts of the world. There has been a growing trend of pet ownership globally as pet ownership is linked with two of the well-being measures (self-esteem and locus of control) (Hecht et al., 2001) as well as physiological and psychological health benefits (O'haire, 2010). These days, living organisms are used for assistance as well as for therapy eg. AAT (animal-assisted therapy) (O'haire, 2017). Growing demand for these animals for domestic pet prompts a complex, lucrative, and often illicit international trade in wild-caught animals (Daut et al., 2015). The exotic pets may be sourced directly from the wild, taken from the wild as eggs, born in captivity from wild parents, reared in captivity or bred in captivity (Bush et al., 2014).

The primary international wildlife trade legislation is the Convention on the International Trade in Endangered Species of Wild Flora and Fauna (CITES), which regulates trade in over 35,000 species of plants and animals (CITES, 2013). Therefore, trade in CITES-listed species comprises an important subset of the global trade in wildlife products. The estimated value of key trade in of animals listed in CITES Appendix II is estimated to range from between US $350-530 million per year (CITES, 2012).

Several species mammals are traded as live animals for pet and for trophies as well as for their parts and derivatives. Approximately 321,700 mammal trophies of Appendix II-listed species were exported during the period 1996-2010 (CITIES, 2012). Over 4.6 million mammal skins were exported for commercial purposes over the period 1996-2010 and vast majority (>99%) were sourced from the wild (CITES, 2012).

- Bird trade represents the major trade of live animals and is primarily for the pet trade. Bodies, feathers and eggs, as well as other parts and derivatives, are also traded at notable levels. Over five million live Appendix II birds were exported during the period 1996-2010 (CITIES, 2012). Overall, 86% of all birds exported were from the family Psittacidae.
- Reptiles are traded in many different forms, but the main trade is in live animals and skins. Over 19.4 million live Appendix II reptiles were exported during the period 1996-2010 (CITIES 2012). Approximately 44 million reptile skins were exported between 1996 and 2010, with 65% of these harvested from the wild and the remainder primarily captive-produced (32%) (CITES, 2012).
- Amphibians are primarily traded as live animals, approximately 540,000 live, Appendix II amphibians were exported during the period 1996-2010 (CITES, 2012). Of these, roughly 64% were harvested from the wild and 33% were captive-produced.
- Excluding coral, over five million live invertebrates were exported during the period 1996-2010. Of these, roughly 55% were captive-produced and 38% were harvested from the wild (CITES, 2012). Pet fish are used in aquarium, Currently, more than 2500 species of ornamental fish are commonly traded, near half are marine species (VK Dey 2016; Moorhead and Zeng, 2010).
- Approximately 27.5 million kg of coral (recorded as both live and raw corals) were exported during the period 1996-2010, with the vast majority (98%) harvested from the wild (CITES, 2012).

The ornamental sector of horticultural industry has a global economic value of USD $250-400 billion (Chandler and Sanchez, 2012). In 2013, global exports of cut flowers, cut foliage, living plants and flower bulbs amounted to USD 20.6 billion (Rabobank, 2015). **Ornamental plants** are used in gardening, landscaping in households or as cut flowers based on their morphology and flower (Azadi et al., 2016). They are also used in public parks, botanical and zoological gardens. In some religions and traditions, flowers are offered to deities. Over 968 million live Appendix II plants were exported during the period 1996-2010; of these, 77% were artificially propagated and 23% were wild-sourced (CITES, 2012). In 2013, global exports of cut flowers, cut foliage, living plants and flower bulbs amounted to USD 20.6 billion (Rabobank, 2015). Orchids, one of the largest plant families, are widely used plants traded for a variety of purposes including as ornamental plants, medicinal products, and foods (Hinsley et al., 2017).

Likewise, many materials are associated with cultural, tribal and religious ceremonies. Cowry, a group of small to large sea snails, marine gastropod molluscs belongs to Cypraedae family, is often referred to its' shells. It is used to make jewelry and used as ornaments. It is viewed as symbol of womanhood, fertility, birth and wealth (Boone, 1986). Cowry shells are used for gambling in various region including Nepal. In some areas, it is used for ancestral offering and kept as a symbol of fortune (https://en.wikipedia.org/wiki/Cowry).

Birds are used for hunting in many parts of the world (Soma 2014). The Dene people of Alaska have traditionally trained ravens, hawks and other birds of prey to sight and hunt game for them, but also to alert them of danger (Magnus and Syanberg, 2017).

13.3. (Co-) production

13.3.1. How is this NCP produced?

Materials derived from forest, agro and aquatic ecosystems are the result of the biotic production functions of nature combined with human intervention. People have to invest time, labor, technology, and energy to harvest/cultivate the materials and tame organism grown in nature. When materials are used as an input (i.e. raw materials) to the production processes, they require knowledge, skills, financial capital, institutions, and technology acquired and developed by humans. For example, timber used for building and construction as well as production of papers and wallboards are co-produced by human inputs of labor, capital, technology, machinery combined with biophysical infrastructure (e.g., woodland) and ecological processes (e.g., photosynthesis) (Fischer and Eastwood, 2016). Plant (cotton, hemp, jute) and animal fibers (silk, shatoosh) are used for cloth production and textile industries require human inputs of labor, nutrients and pesticides, energy and technology as well as the traditional knowledge gathered from our experience since millennia. In the case of cotton production system, human inputs are perhaps more pronounced than the natural ecological state. Because, this system is heavily relied on modern technology in order to produce genetically modified cottonseeds, control weeds and insects by using herbicides and pesticides, develop irrigation systems. It also requires a complex harvesting and processing system as well as a value chain for trading (institutions) to deliver final products (i.e. textiles) to people.

The productivity of nature to produce materials depends on available solar inputs, photosynthetic activity and energy transfers that take place at different trophic levels within the relevant ecosystems as well as the inputs from human knowledge and technology (http://www.ecosystemservicesseq.com.au/step-5-services/building-and-fibre). Nature provides source stock and the necessary inputs/conditions that allow cultivated plants and animals to thrive. Humans use their experience, knowledge and skill to manipulate (i.e. breeding, selection, gene editing) biotic productivity of nature to produce in greater quantities and desired characteristic than that available under the natural conditions.

To use ornamental resources collected from nature requires human ingenuity in each step of collecting, curating, crafting, shipping, selling, buying and preserving of ornamental resources. Furthermore, ornamental plant and pets were domesticated and produced by hybridization and artificial selection, in some cases genetically engineered and produced in a mass scale.
Functions such as pollination, biological control, food, water supply and landscape opportunity are recognized as important functions of nature for providing ornamental resources. These functions are important to the reproduction, maintenance, growth and decay rates, and resilience of species and ecosystems (http://www.ecosystemservicesseq.com.au/step-5-services/building-and-fibre).

Nature supports populations of wild animals, people have developed various kinds of tools and techniques to collect, capture and tame species. All the material resources such as woods, fibers, waxes, resins, dyes, pearls, shells, and coral, latex were co-produced and some of them are predominantly derived from the plantations forestry and agricultural system in which humans have dominating role to produce material goods.

Summary of how this NCP is produced:

- ***Direct***: All the materials derived from forests, agro-ecosystems and aquatic ecosystem are produced directly.
- ***Indirect***: There are no indirectly produced materials

13.3.1.1. Links to other NCPS

NCP 1- Habitat creation and maintenance

Production of materials has both positive and negative impacts on Habitat. Areas that are intensively managed for producing materials such as forest plantations, agro-ecosystems, and aquaculture may produce habitat for several other species. Although conversion of natural forests and afforestation of natural non-forest land is detrimental, plantation forests provide valuable habitat, even for some threatened and endangered species (Brockerhoff et al., 2008). In addition to materials, plantation forests provide direct and indirect benefits to biodiversity via the provision of forest habitat for a wide range of species (Pawson et al., 2013). However, land use conversion for cotton and rubber farming has negative effects on the habitats. Although conversion of natural forests or swidden agriculture to monoculture rubber plantation negatively impacts biodiversity, rubber agroforests in some areas of Southeast Asia support a subset of forest biodiversity in landscapes that retain little natural forest (Warren-Thomas, 2015). Illegal logging in tropical forest caused biodiversity loss particularly threatened habitats of orangutan in Indonesia (Wich et al., 2011) and Siberian tiger (EIA, 2013). Increasing production from plantations and agroecosystems that leads to expansion in land area and will reduce the amount of native forests and grasslands.

NCP 2. Pollination and propagule dispersal

Materials derived from plants depends on the pollination services for reproduction. Although cotton is a self-fertile and self-pollinated plant, the production will increase if it is cross-pollinated by honeybees (Rhodes 2002). Rubber tree (*Hevea brasiliensis*) is pollinated largely by midges of the family Heleidae (Warmke, 1952) and *Ficus elastica* is pollinated by wasp (Harrison et al., 2017).

NCP 3 – Regulation of air quality

Vegetation can filter pollutants, can also emit various compounds that contribute to pollution, and plants and animals can be damaged by air pollution.

NCP 4 – Regulation of climate

Forest plantations primarily aimed at producing wood and construction materials can play a key role to mitigate climate change through direct carbon sequestration or by avoiding deforestation (Paquette & Messier, 2010). Cultivation of materials such as cotton helps to store carbon. Therefore, net carbon emission in the cotton-growing region is negative as cotton plants absorb more carbon than is released from production inputs (i.e. synthetic fertilizer, electricity and fossil fuels used to power irrigation pumps) during growth (Cotton Australia, 2016). Bamboo and rubber plantations have carbon storage function and can be valued as a carbon sink (Yuen et al., 2017). Conversion of native forests and grasslands into production system to produce materials releases carbon.

NCP 5- Regulation of ocean acidification

NCP 6- Regulation of freshwater quantity, location and timing
Cultivation of materials such as cotton deteriorates water quantity and quality. Cotton consumption is responsible for 2.6% of the global water use and about 84% of the water footprint of cotton consumption in the EU25 region is located outside Europe, with major impacts particularly in India and Uzbekistan (Chapagain et al., 2006). Due to extensive use of water for cotton, major river systems of the world such as in Australia and India are depleting water flows and ground water in those areas is dying out (WWF, 2013). Forest plantations reduce local water availability (van Dijk and Keenan, 2007)

NCP 7- Regulation of freshwater and coastal water quality
Cotton is the primary source of agriculture pollution in cotton growing regions of the world. Only 2.4% of the world's arable land is planted with cotton, yet cotton accounts for 24% of the world's insecticide market and 11% of the sale of global pesticides and 50% of the pesticides used in developing countries are for cotton (WWF, 2013). Runoff of pesticides, fertilizers, and minerals from cotton farms contaminates aquatic systems and underground aquifers.

NCP 8 - Formation, protection and decontamination of soils and sediments
Industrial scale plantations of fast growing timber trees and natural rubber plants have converted forests or swidden agriculture to monocultures decreased soil organic carbon stocks (van Straaten et al., 2015). Cotton cultivation also degrades soil quality.

NCP 9 - Regulation of the impacts of hazards and extreme events
Plantation forests that supply materials resources also help for regulation of the ecological functions such as hydrological cycle and micro-climatic condition. Hazards also affect the loss of materials resources.

NCP 10 - Pest, disease and stree regulation
Materials such as timber and fibers useful for humans assist spreading of pests and some companion animals act as a vector to transport pests and diseases, which in turn affect the production of other materials. Global trade of ornamental plants and pet animals (i.e. birds and aquatic fishes) have prompted biological invasion (Carrete and Tella, 2008). Those transported animals act as a vector of diseases affecting human health (Patoka et al., 2016, Chang et al., 2009).

NCP 11- Energy
Materials are also used to generate energy while energy input is necessary to produce materials. The use of wood pellets for electricity generation and heat are increasingly used in recent years. Biomass-based is the largest source of renewable energy worldwide, accounting for an estimated 8.9 per cent of world total primary energy supply in 2014 (UNEP 2016). More than 200 billion people particularly in developing countries, depends on wood energy for cooking and heating (http://www.fao.org/forestry/energy/en/).

NCP 12 -Food and Feed
Several materials have multiple uses and can be used as medicine and food. Bamboos shoot is used as a food and medicine.

NCP 14 -Medicinal, biochemical and genetic resources
Tree bark is widely used in pharmaceuticals or insecticidal, fungicidal or similar products. Turpentine (resin obtained from Pinus) is used in pharmaceutical industry (Sorrenti, 2016). Ornamental plants are used as food and medicine, gene for biotechnology as well as education purpose in botanical and zoological gardens.

NCP 15 -Learning, artistic, scientific and technological inspiration
Ornamental plants are used as food and medicine, gene for biotechnology as well as education and research purpose in botanical and zoological gardens.

NCP 16 -Physical and experiential interaction with nature
Apart from the consumptive uses of materials, materials are used for learning and experience. For example, pets are used as materials for education and good experience. Birds are kept for amusement for their songs, birds used in song contests and birds in blood sports (Magnus and Svanberg, 2017).

NCP 17-Symbolic meaning, involving spiritual, religious, identity connections, social cohesion and cultural continuity
Natural materials are used for spiritual, religious, symbolic purposes in many cultures. Materials such as Elephants and oxen used for transportation or other laborious task due to physical tasks were revered in Hindu religion. Oxen is regarded a vehicle of Lord Shiva and considered as sacred animals whereas Elephant is regarded as a vehicle of Indra and considered as 'the elephant headed God', Shri Ganesh. Among the Balkan culture, swaddling an unmarried person in a horse-girth is a typical ritual. It is thought that the sexual potency of the horse is passed to the individual wrapped in its girth (Vukanovic, 1980). Hawk also used in falconry is treated as a god in North Borneo (Waterbury 1952).

13.3.2. How is it measured?

As there are several sub NCPs in Materials and assistance, different indicators are used to measure the co-production of different materials and companion organisms. In some cases, there are more than one indicator to measure a single material. For instance, animals traded for pet are measured by counting the number directly and diversity of the traded species as well as their market value. Likewise, timber production can be measured in cubic meters per hectare per year or tons of forest biomass production by per unit area of forest. The indicators used here (Table below) for different material resources are based on the data availability and their ability to communicate information about characteristics, state and trends. Materials used for local household use have different indicators and some indicators cannot be extrapolated to larger (global or region) scales such are loads of fodder collected by a person to feed livestock. However, most of the measurement of indicators for materials are universal. Yield or production of materials is measured spatially in per unit area (ha). Here, the indicators used to measure materials are used to measure the flow of materials NCP, not the stock. For example, timber production is measured by the quantity of timber harvest expressed in volume of wood per unit area and per unit time (m3/ha/year) not by the stock of timber in forest. Likewise, the amount of cotton harvested are measurement of the flow of cotton harvested by farmers.

13.3.2.1. Indicators of NCP (co-) production

Sub NCPs	**What to measure (Indicator/Proxy)**	**Rationale/ justification for why this indicator/ proxy was selected**	**How to measure (method)**			**Data set**
			Direct	Indirect	Model	
Timber	Timber harvest (m3/ha/year)	Data availability	Forest stand measurement	Remote sensing of biomass using NDVI	Timber Production models	FAO
Grass/Fodder	kg	It is the easiest/no data available at measurable scale				N/A
Bamboos and rattans	Market value	Data available				FAO/INBAR
Gums	Kg	Data available	Direct measurement after extraction and national statistics			Commodity Trade Statistics Database, United Nations Statistics Division

Resins	Kg	Data available	Direct measurement after extraction and national statistics			Commodity Trade Statistics Database, United Nations Statistics Division
Latexes	Kg	Data available	Direct measurement after extraction and national statistics			Commodity Trade Statistics Database, United Nations Statistics Division
Oil	Kg	Data available	Direct measurement after extraction and national statistics			Commodity Trade Statistics Database, United Nations Statistics Division
Waxes	Kg	Data available	Direct measurement after extraction and national statistics			Commodity Trade Statistics Database, United Nations Statistics Division

Tannins	kg	Data available	Direct measurement after extraction and national statistics			Commodity Trade Statistics Database, United Nations Statistics Division
Dyes	Kg	Data available	Direct measurement after extraction and national statistics			Commodity Trade Statistics Database, United Nations Statistics Division
Cork	Kg	It is the easiest, data available at certain country level	Direct measurement after extraction and national statistics			FAO
Bark	Kg	It is the easiest, data available at certain country level	Direct measurement after extraction and national statistics			
Cotton	Cotton bale Yields (t/ha)	Data available	Field measurement and agricultural statistics		Crop production model	
Flax	Yields (t/ha/year)	Data available	Field measurement and agricultural statistics		Crop production model	

Jute	Yields (t/ha/year)	Data available	Field measurement and agricultural statistics		Crop production model	
Sisal	Yields (t/ha/year)	Data available	Field measurement and agricultural statistics		Crop production model	
Hemp	Yields (t/ha/year)	Data available	Field measurement and agricultural statistics		Crop production model	
Silk	Cocoons (t/hear)	Data available	Field measurements and agricultural statistics			
Coral	Solid units (number/year) Number of species	Data available	Field measurements and surveys of people harvesting/trading pet fish			Commodity Trade Statistics Database, United Nations Statistics Division
Pearls	Sold units (number/year)	Data available	Field measurements and surveys of people harvesting/trading Pearls			Commodity Trade Statistics Database, United Nations Statistics Division
Shell	Sold units (number/year)	Data available	Field measurements and surveys of people			Commodity Trade Statistics Database,

			harvesting/trading Shell			United Nations Statistics Division
Ornamental plants	Sold units (number/year or kg/year) Number of species	Data available	Field measurements and surveys of people harvesting/trading ornamental plants			Commodity Trade Statistics Database, United Nations Statistics Division
Pet fish	Sold units (number and species diversity/year) Monetary value	Data available	Field measurements and surveys of people harvesting/trading pet fish		Fish population model,	CITES, Bush et al. 2013
Pet bird	Sold units (number and species diversity/year) Monetary value	Data available	Catch measurement		Ecological production model	CITES, Bush et al. 2013
Pet reptile	Sold units (number and species diversity/year) Monetary value	Data available	Catch measurement		Ecological production model	CITES, Bush et al. 2013
Pet amphibian	Sold units (number and species diversity/year) Monetary value	Data available	Catch measurement		Ecological production model	CITES, Bush et al. 2013
Other living organism for assistance	Number, stock density (number of horse/household)	Data available	Direct measurement		Ecological production model	

Data of major material resources are available but need some processing/curation. It can be done after we select material resources.

13.3.3. Trends in Co-Production

13.3.3.1. General (across all units of analysis)

A mixed (increasing and decreasing) trend of co-production of the materials is observed albeit a majority of material resources co-produced by nature with human inputs has increased. The production of materials extracted from forest ecosystems such as timber (i.e. round wood production), gum arabic and resins has continuously increased since 1961 (FAO, 2018). Globally, the timber harvest for industrial use has nearly tripled in the last 25 years, reaching 41 million m^3 in 2013 (FAO, 2016). Most of the industrial timber now is harvested from plantations as forest plantations have become a substantial component of the productive and protective forest resources and play an ever more important part in securing both industrial roundwood and wood fuel (Jürgensen et al., 2014). Planted forests also play a role in offsetting the pressure and negative impacts on natural forests (Payn et al., 2015). Based on the analysis of data of 78 countries, about 46% of global industrial roundwood production in 2012 came from planted forests and semi-natural planted forests (Jürgensen et al., 2014). The area of planted forests has increased by 7% (105 million ha) between 1990 and 2015 varying by country and region (FAO, 2016). Nevertheless, there has been a net decrease in global forest areas from 4128 million ha to 3999 million ha (of 3.1%) between 1990 and 2015 (Keenan et al., 2015). Although total natural forest areas have decreased globally particularly in tropics and subtropics, forest areas in boreal and temperate zones have increased and the forest productivity has increased globally over the period (Payn et al., 2015). About 93% of the global forests are the natural forest in 2015 (MacDicken, 2016). The production of bamboo, more than half of which is produced in Asia, has also increased by 11% since 1990 (FAO, 2010). Production of rubber that mostly comes from plantations areas has also increased (FAO, 2018). The production of gum Arabic has increased since 1988 and the rate of increase after 2006 is slow (United Nations Statistics Division, 2018).

A similar mixed trend is observed for the materials derived from the agro-ecosystems. The majority of fiber crops that derived from agro-ecosystems such as cotton, agave, coir and silk production has increased since 1961 whereas the production of other fibers (hemp, sisal, bastfibers) has decreased or remain same (Jute, Manila). The production of cotton has nearly doubled since 1961. However, the cotton growing area has remained almost the same as the productive has increased due to the use of improved seed varieties, sophisticated irrigation facility and use of pesticides and herbicides (Cotton Australia, 2016). Likewise, the production trend of ornamental flowers and cut flowers has increased but the rate of increase is slow in recent years (UN TRADE DATA). There is an increasing demand for plants used to extract natural dyes and colorants as manufactures continue to look for alternative of synthetics (Lubbe and Verpoorte, 2011).

Most of the materials derived from the aquatic ecosystems such as coral, pearls, shell and pet fish have increased. The hobby of aquarium is increasing worldwide causing a rapid growth of the aquatic ornamental industry (Moorhead and Zeng, 2010). The global export of ornamental fish has been growing continuously from US$177.7 million in 2000 to a peak of US$364.9 million in 2011, then declining slightly to US$347.5 million in 2014 (Dey, 2016). Currently, almost all (90-99%) of marine aquatic organism traded for pet industry comes from wild-catch whereas the 90% of the fresh-water counterparts are bred in captivity (Moorhead and Zeng, 2010). UN commodity trade data shows that both export and import of natural pearls have increased since 1988.

Floriculture trade (flower bulbs, cut foliage, cut flowers and living plants) has increased continuously since 1988, reached at the peak in 2011 then declined (75. United Nations Statistics Division. 2018; Rabobank, 2015).

Normally the use of materials for transpiration, ploughing and other production tasks is declining and is replaced by machinery and mechanized equipment.

Because of the illicit nature of wildlife trade, it is very hard to estimate the exact volume of wildlife traded for pets. However, a systematic review of the literature and CITES trade data helped to estimate the trade patterns of live exotic birds, mammals and reptiles (Bush et al., 2014). According to the CITES database, from 1996 to 2010, the overall volume of trade in CITES Appendix II live animals and plants peaked in 2000 and 2006, respectively with a decline seen since then. The decrease in 2009-2010 reflects delays in reporting of trade data and, potentially, global market factors (CITES, 2012). Nevertheless, the number of exotic pet ownership has increased globally. For many taxonomic groups (mammals, birds, reptiles, amphibians, fishes), there was a notable increase in the number of captive-produced or ranched specimens in trade with a decrease in the number of wild specimens (CITES, 2012).

Generally the trade levels of the mammals hunting for trophies have remained constant since 2000 (CITES, 2012). According to the CITES database, the trade of skins of mammals has been decreasing since 2007 and the decrease in 2009 can largely be attributed to a 91% decrease in exports of fox skins, Lycalopex species, by Argentina (CITES, 2012).

Roughly, 62% of the CITES indexed birds were produced in captivity and remaining 38% are harvested from the wild (CITES, 2012). From 1996 to 2010, exports of live birds peaked in 1999 with a subsequent decrease afterward. Since 2006, there has been an increase in the number of captive-produced live birds in trade (CITES, 2012). According to CITES database, globally, wild bird exports have remained below 100,000 birds annually since 2006 but have increased slightly, primarily due to an increase in the export of wild-sourced Monk Parakeet *Myiopsitta monachus* from Uruguay to Mexico, and smaller increases in exports of other parrots.

Reptiles traded for exotic pet are declined by one third from 2001 to 2012 (CITES, 2012). About 96.8% of the reptiles traded globally were captive-bred (63%), ranched (14%) or sourced from the wild (23%). Following the peaks in 1996 and 2001, the overall imports decreased by 32.8% from 2001 to 2012 at an average rate of 3.4% per year (Robinson et al., 2015). Although the decreased was the highest in wild-caught reptiles, captive-bread reptiles also decreased (40%). In contrast, there was a nearly 50-fold increase in imports of ranched reptiles, dominated by royal pythons from sub-Saharan Africa, but including a recent upsurge of ranched turtles from South America and Asia (Robinson et al., 2015). The greatest decline in wild-caught reptiles (70%) followed by the in captive bred reptiles (40%) (Robinson, 2015). However, a general increase in trade in ranched animals is evident, in large part due to an increase in exports of Python regius from West African countries. The Green Iguana, *Iguana iguana* represented 54% of exports; most of the trade in this species involved captive-produced animals (CITES, 2012). CITES database showed that export of reptile skins has also decreased since 2006 (CITES, 2012).

Exports of live amphibians fluctuated from 1996 to 2010, primarily due to variability in the quantity of exports of Mantellidae from Madagascar, combined with an anomalously high level of wild-sourced exports by Panama in 2006 (Dendrobates auratus and D. pumilio) (CITES, 2012). The trade of amphibians particularly Southeast Asian newt has also declined from 2005 to 2014 (Rowley et al., 2016).

According to CITES database, exports of live invertebrates excluding coral from 1996 to 2010 peaked in 2002 and again in 2007 then declined. Trade in corals increased from 1997 to 2004 and has remained constant since 2005. The apparent decrease in 2009 and 2010 can be attributed to missing annual reports for these years from the second largest coral exporter at the time of analysis (CITES, 2012).

From 1996 to 2010, exports peaked at 120 million plants in 2006 with a decrease seen since then, wild-sourced exports remained below 30 million plants annually throughout the period (CITES, 2012). According to the CITES trade database, the trade of live orchid sourced from wild has declined continuously from 1996 to 2008 and then increase to 2015 reaching at the peak in 2014 (Hinsley et al., 2017).

- ***Spatial variance***

There is a huge spatial variation among the trends of different material resources. In some countries and regions, the production amount has decreased whereas in others, it has increased. The rates of increase or decrease vary with countries and regions. Over the last 25 years, the area of planted forest has increased in all climatic domains, most notably in the boreal domain, where it has almost doubled. In the tropical and temperate zones, it increased by 67 percent and 51 percent, respectively (MacDicken, 2016). Half of global forest area is in sub-regions where forest cover is expanding: Europe, North America, the Caribbean, East Asia, and West and Central Asia. The remainder is in sub-regions where forest area continues to decline: Central America, South America, South and Southeast Asia and all three sub-regions in Africa. Oceania (dominated in area by Australian forests) showed periods of gains and losses in forest area between 1990 and 2015 (Keenan et al., 2015).

Out of the total rubber produced globally, 91.2 % came from Asia, 5.3% from Africa, and 3.4% from Americas and 0.1 from Oceania. Rubber production and area harvested has been continuously increased in Asia (FAO, 2018).

Likewise, the production of jute in India and Bangladesh has increased whereas the production of sisal in Angola has decreased significantly since 1970 (FAO, 2018).

The ornamental fish imports has been declined from US$ 60 million in 2000 to US$ 36.8 million in the USA—the world's largest single market for ornamental fish (Dey, 2016). Similar trends of continuous decline was observed in the Japanese market, while in the Europe, import has been increased continuously from 2000 to 2008 then declined (Dey, 2016).

In the wildlife trade, a shift in regional patterns over time was observed causing a market fluctuation (Robinson, 2015). Here are some regional trends of production/supply of major wildlife traded for pets. The data were derived from cites database (CITES, 2012).

- The principal exporter of mammal trophies, accounting for 61% of the trade, was Canada (194,581). Exports from Canada decreased throughout the period from 106,700 trophies during 1996-2000 to 46,100 trophies during 2005-2009 (2010 data not yet available).

- The main exporters of live birds, accounting for 61% of the trade, were South Africa (1,081,632), China (884,074), Netherlands (452,934), Cuba (362,040) and Uruguay

(301,176). China was the top exporter for the period 1996-2000, but has not reported the export of any live birds since 2004. Uruguay was the top exporter of wild-sourced live birds, accounting for 15% of the trade; most of this trade occurred since 2006.
- The main exporters of live reptiles, accounting for 68% of the trade, were El Salvador (7,342,770), Colombia (2,923,871), Ghana (1,125,474), Benin (964,930) and Indonesia (876,407). In the most recent five years (2006-2010), the quantity of live reptiles exported by Colombia and Benin has decreased substantially.
- The proportion of invertebrates exported by the Russian Federation (all Hirudo medicinalis) increased during the period, making it the second most important exporter in terms of volume 2006-2010. Ghana and Viet Nam were the principal exporters of live, wild-sourced invertebrates, each accounting for 44% of the wild-sourced trade. Benin and Togo were the major exporters of ranched invertebrates, accounting for 41% and 29% of the trade, respectively.

- ***Degree of certainty***:

There are three major sources of data for material NCP: FAO database, UN commodity trade database and CITES trade database (Appendix II) of traded specimens of plants and animals as well as the parts derived from them. Although the data for material NCP were freely available, are collected/managed for a long period (FAO data is available from 1961, UN Trade data from 1988 and CITES from 1975) and are global in coverage, the quality of the data remains a challenge. For example, the FAO data on roundwood production are not consistent and too fragmented therefore roundwood production from plantations could only be estimated for 17 countries for which reported data were available for a period of several years (Jürgensen et al., 2014). Forest resource assessment (FRA) published by FAO relied on the country reports and 40% of the FRA data are reported to be based on the medium (Tier 2) or low (Tier 1) quality (Romijn et al., 2015). According to Keenan et al.(2015), out of 99 tropical countries only 54 countries have good capacities to monitor changes in forest area.

CITES database that holds records of 13 million records of trade in wildlife of 34000 species managed by UNEP world conservation monitoring centre is based on the annual report of the 178 CITES parties. Based on the CITES convention, CITES parties need to submit the annual report of the trade of species to the CITES secretariat. Many annual reports do not clearly state whether the data were derived from the actual number of specimens traded or from the quantity for which the permits or certificates were issued (CITES, 2013). Likewise, reports lack information on seized or confiscated species, information on the source of materials (wild vs captivity), use non-standard units to describe the volume of articles (CITES, 2013). Despite this challenge, those data sources were widely used in research and the most reliable and comprehensive source of information available yet. Despite the recent growth and diversification of the aquarium trade, data collection to date, is not mandatory, and hence comprehensive information on species volume and diversity is lacking (Rhyne, 2017). The CITES trade database only provides the subset of the global trade of plants and animals species as it captures legal reported trade and does not capture illegal trade (CITES, 2012). Furthermore, thousands of traded species are not listed in the CITES (Dee et al., 2014). The nature of most of the wildlife trade is implicit and shrouded in secrecy. Hence, it is hard to estimate the accurate extent of trade.

Summary of NCP trends:

- ***Trend***:

Historically, materials were extracted solely from the natural environment with low inputs from humans. However, an increasing portion of material resources is now sourced from plantations, agro-ecosystems, and captive breeding where human inputs are comparatively higher. There is an increasing trend of substituting the materials extracted from nature by the materials grown or planted in artificial setting or by synthetic materials. Forest plantations is now the major source of industrial timber, rubber and bamboos. Almost all of the natural fibres used for textiles and manufacturing come from cultivation. Synthetic fiber plays important role in global textile industries and shares 62.7% of global fiber market in 2016 while cotton and wool shares only 24.3% and 1.1% respectively (http://www.lenzing.com/en/investors/equity-story/global-fiber-market.html). For many taxonomic groups of plants and animals traded globally for pet, there was a notable increase in the number of captive-produced or ranched specimens in trade with a decrease in the number of wild specimens. Even though there is an increasing portion of material resources sourced from artificial setting, the primary materials to propagate, culture or bread such as seeds, eggs, and parents are derived from wild.

- ***Spatial variance***:

There is a wide range of spatial variation. Due to the diversity of material NCP, it is hard to produce a cumulative pattern of spatial variation. Most of the cases, the materials sourced from wild in tropical and subtropical regions are decreasing.

- ***Degree of certainty***:

High degree of certainty of trends of various materials particularly in developed countries. Tropics, which is the source of major traded species, the certainty is low.

13.3.3.2. By Units of Analysis

Unit of Analysis	**Direction of arrow**	**Rationale/ justification for why you think this trend is happening**
1. Tropical and subtropical dry and humid forests LUC: Deforestation	Down Up Down	LUC: Multispecies forest to cropland/monoculture plantations, less wild harvest. The deforestation is still high in tropical and sub-tropical region. Trade species of birds, reptiles, orchids, amphibians were sourced from wild. Management: Shifts to tree plantations in tropics (rubber and other fast growing tree species, bamboos) Management: Soil degradation and decreasing yields maybe?
2. Temperate and boreal forests and woodlands LUC: Deforestation	UP	LUC: the forest areas in boreal region are increasing and deforestation is decreasing.

10. Cultivated areas (including cropping, intensive livestock, farming, etc.) LUC: Conversion from grassland LUC: Conversion from Forest Management: More intensive agriculture	UP	Cotton, roundwood, jute, cut flower, pearls production have increased. Likewise, the trade of exotic species of pet (mammals, birds, reptiles, amphibians) has also increased as most of them are now grown in captivity or reared in ranch. The productivity of cotton and planted forests has increased due to the intensive agriculture, improved variety of seeds, fertilizer, pesticides/herbicides.

13.4. Impacts on good quality of life

13.4.1. Different types of value

13.4.1.1. How does it contribute to good quality of life?

Materials are the basis for production system providing raw materials for many industries such as textiles, furniture, arts and crafts, fibers, and timber. Timber alone is used to produce more than 5,000 types of wood-based products (World Bank, 2017). Materials used for clothing and housing are dominant products in world economy and for human usage both in terms of volume of production (tonnage) and in terms of value. Materials help to create jobs, fulfill the provisioning materials for human needs and survival. They are the sources of inspiration, materials for arts and crafts, education (botanical/zoological garden) and non-material wellbeing (spiritual, cultural and identify). In many cases, materials provide income to local people, help create employment and are source of export to countries.

Economic

The formal timber sector employs more than 13.7 million people worldwide, equivalent to 0.4% of the total labor force (ILO, 2017). According to ILO, Ten countries (China, USA, Brazil, Russia, India, Japan, Germany, Indonesia, Italy, and Malaysia) concentrate more than 60% of the total employment (including the three sub-sectors: logging, wood processing, and pulp & paper). Out of these, China, with 3.5 million formal jobs in the sector, accounts for 26% of the world employment. Timber sector generates a gross value added of over $600 billion each year and the part of the contribution to economy is underreported, as the sector is mainly informal (World Bank, 2017). Apart from formal job creation, small-scale forest product processing, such as wood carvings or cane furniture, may be an important source of non-farm employment in many developing countries (Lambrechts, 2008). Likewise, other material resources also help create employment and livelihood opportunities through income generation. Textile sector in India plays a pivotal role through its contribution to industrial output, employment generation and the export earnings of the country. In 2008, it contributed about 14% of industrial production, 4% of the GDP and provided direct employment to over 33 million people (Cotton Fact Sheet, 2009). Textile sector has potential to create 45-50% of direct jobs in the rural India (Hindu 2015).

Health

Companion animals have positive health benefits to human. Human-animal interactions can remarkably enhance human physical health (by facilitating improvements in cardiovascular health and physical fitness) and psychological well-being (O'haire, 2010; Smith, 2012). Companion animals help owners cope with pain in many ways, including provision of social and emotional support and by providing a sense of purpose in life (Bradley & Bennett, 2015). Companion parrots appear to provide much emotional support, joy, and routine (Anderson, 2014). Pet ownership also helps development of immune system as exposure to pet lowers the likelihood of developing allergies and it enhances social health due to the role pets can play as social enablers (Smith, 2012). Visiting zoos and aquariums and interacting with animals will decrease mental stress in humans (Sahrmann et al., 2016). Animal-assisted interventions have been successful at improving the mental health and quality of life for persons with developmental, neurological, social, and psychological impairments (Hart, 2006). There has been an increase evidence that present the animal assisted intervention for autism showed a consistent increase social interaction among children (O'Haire, 2017). However, some negative effects of companion animals to human are also reported. Potential transmission of infectious diseases, source of allergies, mammalian bites are the adverse health effects of companion animal ownership (Smith, 2012). Trade of various animals such as Birds will assist in spread of pathogens such as Avian influenza (Edmunds et al., 2011).

Socio-cultural

The pearls (Mani and Mukta from Sanskrit) is described as sacred in Hindu scriptures and mentioned in Garuda Purana, New Testament scripture and Islamic scriptures. Pet animals such as dogs are worshiped in Nepal by Hindu communities.

13.4.1.2. How do we measure contribution?

Several methods of measuring the impact of materials are available but the widely used method is measuring monetary value of extracted materials. In most of the cases for the materials extracted for forest, agro and aquatic ecosystems, this method is used. Employment (formal and informal) created while co-producing materials is another way to measure impact in production sector. Counting the number of health benefits of having companion animals and counting cultural/religious activities relying on materials are another way to measure the impacts. However, those methods are not used in the literature.

13.4.1.3. Substitutability

Historically, materials were extracted solely from the natural environment with low inputs from humans. However, in recent time, the reliance on nature to produce materials is decreasing as an increasing portion of material resources is now sourced from the human-modified environment such as plantations, agro-ecosystems and captive breeding where human inputs are comparatively higher. There is an increasing trend of substitution for the materials provided by nature by the materials grown or planted in an artificial setting. Forest plantations are now the major source of industrial timber, rubber, and bamboos. Almost all of the natural fibers used for textiles and manufacturing come from cultivation. For many taxonomic groups of plants and animals traded globally for pets, there was a notable increase in the number of captive-produced or ranched specimens in the trade with a decrease in the number of wild specimens. More than half of reptiles (63%), birds (62%), invertebrates (55%) are produced in captivity and more than 3 quarter of plants (77%) traded are propagated artificially (CITES 2012). Even though there is an increasing portion of material resources sourced from artificial setting, the primary materials to propagate, culture or bread such as seeds, eggs, parents are derived from wild. Yet, 23% of reptiles, 38% of invertebrates, 38% of birds and 23% of plants were sourced from wild (CITES, 2012). A complete substitute of some of the materials are available for example colorants and dyes, resins, rubber are produced synthetically these days. Synthetic rubber as natural rubber extracted from the tree is used in automotive industry for ties, door and window profiles, hoses, belts, matting and flooring. Plastics are used as a substitute for woods. Synthetic fibers such as nylon, polyester, acrylic and polyolefin are used as a substitute of natural fibres. Globally, Synthetic fiber is consumed almost three time more than the cotton (http://www.lenzing.com/en/investors/equity-story/global-fiber-market.html). Although substitutes are available, the preference to natural ones is increasing. Natural rubber is preferred for many products, with 70% of global consumption used in tyres (Clay 2004).

The usage of animals for transpiration, ploughing and other production tasks is replaced by machinery and mechanized equipment.

13.4.2. Indicators of NCP impact

13.4.2.1. Indicators by value

Value type	Indicator / Proxy	Rationale / justification for why we this indicator / proxy was selected	Data set	Scale of Measure – space	Scale of measure - time
Health	Health benefits provide by companion animals	There are no time series data available	O'haire, 2010, O'haire, 2011	Systematic review (not available at country scale	
Economic	Supply of fiber crops, resins, gum arabic	Good datasets available for production volume of Agave fibers, coir, cotton, fibre crops nes, flax fibre,	http://www.fao.org/faostat/en/#data/QC	Global or major producing countries	1961-2016

		gums, hemp, jute, rubber, sisal,			
	Trade of silk	Import and export data	data.un.org/Data.aspx?d=ComTrade&f=_l1Code%3a51	Global or major producing countries	1988-2016
	Production of industrial roundwood, paper pulps	Good datasets Production volume	http://www.fao.org/faostat/en/#data/QC	Global or major producing countries	1961-2016
	Export and import of commodity data	Live trees, plants, bulbs, cut flowers	http://data.un.org/Data.aspx?d=ComTrade&f=_l1Code%3a7	Global or major producing countries	1988-2016
	Export and import data	Natural gum, resin, gum-resin, waxes,	http://data.un.org/Data.aspx?d=ComTrade&f=_l1Code%3a14	Global or major producing countries	1988-2016
	Export and import data	lubricants, waxes, candles, modelling pastes		Global or major producing countries	1988-2016
	Pearls		http://data.un.org/Data.aspx?d=ComTrade&f=_l1Code%3a72	Global or major producing countries	1988-2016
	Live animals/ plants listed in cites databases	Number of traded animals/ plants	https://trade.cites.org/	Exporting/Importing countries, Global	1975-2016

13.4.2.2. Trends by user group

Select which user group valued most materials one or two.

Find examples from literature, how would they be affected

User Type	User Group	Direction of arrow	Rationale/ justification for why you think this trend is happening

Universal	Widespread and diffuse impacts	UP	Demands of materials (wood, bamboos and rattans, cotton, rubber), biochemical and biodynamic compounds (gums, resins, latexes etc.), live animals and plants are increasing
Livelihoods	Subsistence and small-scale harvesting (subsistence farming, small-scale farming, grazing, pastoralism, hunting and gathering, artisanal fishing)	Down	Materials used for subsistence, small scale farming are declines as Materials are grown in industrial scale plantations and big farms. Many animals and plants are grown in captivity, farms and ranch hence the materials produced by subsistence farmers are declining. Use of animals for assistance by pastoralist and farmers is also decline
	Commercial harvesting (farming, ranching, fishing, timber)	UP	Many of the aquatic pets are now produced in aquaculture Industrial scale plantations are growing Most of the fibres are produced in commercial level. Most of the materials resources were used in industries such as woods is used in construction industries, fibres are used in apparel industries.
	Recreation and Tourism	UP	Botanical gardens, zoological gardens, aquarium are growing. Number of people having companion animals is also growing
	Industrial, commercial, service, professional	UP	
Household	Urban	Up?	Although there is no specific information available, the industrial production of materials has been growing globally. Therefore, it is inferred that household level usage of materials (timber related products, papers, woods) is increasing. Number of people having pet is increasing.
	Rural	Up?	Although there is no specific information available, the industrial production of materials has been growing globally. Therefore, it is inferred that household level usage of materials (timber related products, papers, woods) is increasing.

			Number of people having pet is increasing.

13.5. Summary

13.5.1. Status

- The production and value of most of the major materials resources is increasing (with some exceptions). As the material wellbeing of people increases due to the increased demand for material resources for population and affluence.

- There is an increasing trend of production of materials sourced from cultivation or intensively managed system than sourced from the wild. Significant proportion of industrial roundwoods, rubber, bamboos are increasingly produced from plantation forests now. More than half of the traded wildlife (birds, reptiles, invertebrates) are sourced from captivity and more than three quarter of traded plants were artificially propagated. However, majority of the traded amphibians and corals were extracted from wild.

- Majority of the natural fibres such as cotton, hemp, jute are produced from cultivated areas. Although synthetic fibers such as nylon, polyester, acrylic and polyolefin are used as a substitute of natural fibres, the demand for natural fibres is continuously growing.

- Although a complete substitute of some of the materials such as colorants and dyes, resins, rubber are available, the preference to naturally produced materials are increasing. For example, Natural rubber is preferred for many products (Clay 2004). There is an increasing demand for plants used to extract natural dyes and colorants as manufactures continue to look for alternative of synthetics (Lubbe and Verpoorte, 2011). The preference for orchids collected from wild is high.

- Most of the materials derived from the aquatic ecosystems such as coral, pearls, shell and pet fish have increased. The hobby of aquarium is increasing worldwide causing a rapid growth of the aquatic ornamental industry. However, the decline in the stock (corals are declining) is apparent in nature and legal provision of protection were put in place which is causing a shift of an increasing trend of fulfilling the demand of aquatic ornamentals from captive breeding and culture.

13.5.2. Similarities and differences across Units of Analysis and across User Groups

- Natural forest areas in tropical and subtropical regions are decreasing while plantation forests are increasing in boreal and some parts of tropics.

- Demands of materials (wood, bamboos and rattans, cotton, rubber), biochemical and biodynamic compounds (gums, resins, latexes etc.), live animals and plants are increasing

- Materials are grown in industrial scale plantations and big farms. Many animals and plants are grown in captivity, farms and ranch hence the materials produced by subsistence farmers are declining

	Potential Nature's Contributions	**Output of the joint production**	**Impact on good quality of life**
Indicator	a) Forest área **b)** Land suitability and extent of cotton producing area	a) Volume of round wood production b) Tonnage of cotton production	a) Number of people employed in forest industry [data available for people involved in selected timber producing countries only] b) Number of people employed in garment industry (include fibre, cotton industry
Trend During the last 50 years: 2 = Major increase (>20%) 1 = Increase (5% to 20%) 0 = No change (-5% to 5%) -1 = Decrease (-20% to -5%) -2 = Major decrease (< -20%)	**a) -1** The forest area over the last 50 yeas has declined globally but it has increased more recently (Song et al. 2018) **b) 0** The área of cotton cultivation remain the same over the last 50 years.	**a) 2** Industrial roundwood production has increased significantly over the last 50 years period but a majority of the roundwood production in recent times is extracted from plantation forests. **b) 2** Despite the Cotton growing región remain the same, the production has increased due to the efficient plantations, improved sedes and irrigation facility.	**c) 1** *Explanation: The total employment in the formal forestry sector decreased by about six percent from 14.0 million in 2000 to 13.2 million in 2011 due to mechanization and reduce in export in selected countries (FAO, 2015).* **d) 1** *Explanation: It is very hard to estimate the actual employment in cotton sector as the developed countries like USA and Australia used heavy machinery in cotton farms while in developing countries such as India and China where cotton farm sizes are smaller have high rate of employment. It is estimated that over 100 million labor force is directly involved in cotton production (Fortucci, 2002).*
Spatial variance 3 = opposite trends in different regions 2 = same directional trends in different regions but of contrasting magnitude 1 = similar trends all over the world	**a) 3** There is a considerable spatial variation in the forest cover change arond the world. Tropics are loosing forest cover while gain was observed in the non tropical parts. **b) 1** Cotton producing áreas are more or les	**a) 2** In some countries, the roundwood production (China) is increased while minor decreased in other countries. Asia-Pacific, Northern America and Europe are the fastest growing region for the roundwood production. **b) 2** Although the magnitude is different the cotton production, it has increase globally	**c) 3** *Explanation: There may be difference among subsistence and small scale harvesting vs. commercial harvesting.* **d) 3** *Explanation: There is a high level of variabilities among cotton employment in developing and developed countries.*

	the same with some minor decrease in the developed countried while increase in the developing countries (China) but the variation is not significant		
Variance across social groups 3 = opposite trends for different groups 2 = same directional trends for different groups but contrasting magnitudes 1 = similar trends for all social groups	NA	NA	**a) 3** *Explanation: There may be difference among subsistence and small scale harvesting vs. commercial harvesting.* **b) 3** *Explanation: There is a high level of variabilities among cotton employment in developing and developed countries.*
Degree of certainty 4 = **Well established**: Robust quantity and quality of evidence & High level of agreement 3 = **Established but incomplete**: Low quantity and quality of	a) 4 The qualitative data are available on forest cover change. However the most recent studies which are based on the remote sensing that do not have	a) 4 FAO data is available for the roundwood production b) 4 Cotton production data are also available in the FAO database.	a) 3 The data on employment in forestry sectory is not robust and limited to the selected timber producting countries. b) 2 There is not data available for the actual employment in the cotton sector globally.

evidence & High level of agreement 2 = **Unresolved**: Robust quantity and quality of evidence & Low level of agreement 1 = **Inconclusive**: Low quantity and quality of evidence & Low level of agreement	data for the 50 year period. b) 4 There is solid evidence of the extent of the cotton growing region in the world.		
Two to five most important papers supporting the reported trend	Global Forest Watch data for forest cover FAO. 2017. Forest Products 2015. Food and Agriculture Organization, Rome (2015) Song, X.P., Hansen, M.C., Stehman, S.V., Potapov, P.V., Tyukavina, A., Vermote, E.F. and Townshend, J.R., 2018. Global land change from 1982 to 2016. *Nature*, *560*(7720), p.639. Source: FAOSTAT-Forestry database	Quantitative data from FAO statistics were used for Roundwood and Cotton.	FAO. 2014. *Contribution of the forestry sector to national economies, 1990-2011*, by A. Lebedys and Y. Li. Forest Finance Working Paper FSFM/ACC/09. FAO, Rome. http://www.worldbank.org/en/topic/forests/brief/forests-generate-jobs-and-incomes

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13.7. Search methodology

I searched in Web of science using following search string

1. (from Web of Science Core Collection)

You searched for: **TOPIC:** (Nature) *AND* **TOPIC:** ("Ecosystem services") *AND* **TOPIC:** (Materials) **Timespan:** All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC. **Results: 74**

2. (from Web of Science Core Collection)

You searched for: **TOPIC:** ("Ecosystem services") *AND* **TOPIC:** (Materials) *AND* **TOPIC:** (woods) **Timespan:** All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC. **Results: 29**

3. (from Web of Science Core Collection)

You searched for: **TOPIC:** ("Ecosystem services") *AND* **TOPIC:** (Materials) *AND* **TOPIC:** (fibres) **Timespan:** All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC. **Results: 12**

4. (from Web of Science Core Collection)

You searched for: **TOPIC:** ("Ecosystem services") *AND* **TOPIC:** (Materials) *AND* **TOPIC:** (papers) **Timespan:** All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC. **Results: 116**

5. (from Web of Science Core Collection)

You searched for: **TOPIC:** ("Ecosystem services") *AND* **TOPIC:** (Materials) *AND* **TOPIC:** (resins) **Timespan:** All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC. **Results: 1**

6. You searched for: **TOPIC:** ("Ecosystem services") *AND* **TOPIC:** (Materials) *AND* **TOPIC:** (dyes) **Your search found no records.**

7. (from Web of Science Core Collection)

You searched for: TOPIC: ("Ecosystem services") *AND* TOPIC: (Materials) *AND* TOPIC: (pearls) **Timespan:** All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC. **Results: 1**

8. You searched for: **TOPIC:** ("Ecosystem services") *AND* **TOPIC:** (Materials) *AND* **TOPIC:** (coral branches) Your search found no records.

9. (from Web of Science Core Collection)

You searched for: TOPIC: ("Ecosystem services") *AND* TOPIC: (Materials) *AND* TOPIC: (coral) **Timespan:** All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC. **Results: 8**

10. (from Web of Science Core Collection)

You searched for: TOPIC: (Nature) *AND* TOPIC: (crops) *AND* TOPIC: (fibres) **Refined by: DOCUMENT TYPES:** (REVIEW) **Timespan:** All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC. **Results: 13**

11. (from Web of Science Core Collection)

You searched for: TOPIC: (crops) *AND* TOPIC: (fibres) **Refined by: DOCUMENT TYPES:** (REVIEW) **Timespan:** All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC. **Results: 300**

12. (from Web of Science Core Collection)

You searched for: TOPIC: ("ornamental fish") **Refined by: DOCUMENT TYPES:** (REVIEW) **Timespan:** All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC. **Results: 32**

13. (from Web of Science Core Collection)

You searched for: TOPIC: ("pet market") **Timespan:** All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC. **Results: 42**

14. (from Web of Science Core Collection)

You searched for: TOPIC: ("pet") *AND* TOPIC: (animal)
Refined by: DOCUMENT TYPES: (REVIEW) AND **WEB OF SCIENCE CATEGORIES:** (ENVIRONMENTAL SCIENCES OR ZOOLOGY OR SOCIOLOGY OR ENVIRONMENTAL STUDIES OR PLANT SCIENCES OR ECOLOGY OR AGRICULTURE MULTIDISCIPLINARY OR AGRICULTURE DAIRY ANIMAL SCIENCE OR EVOLUTIONARY BIOLOGY OR BIOLOGY OR ECONOMICS OR BIODIVERSITY CONSERVATION)
Timespan: All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC. **Results: 59**

15. (from Web of Science Core Collection)

You searched for: **TOPIC:** (Ntfps) **Refined by: DOCUMENT TYPES:** (REVIEW)
Timespan: All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC. **Results: 11**

16. (from Web of Science Core Collection)

You searched for: TOPIC: (Companion animals, Health, wellbeing)
Results: 20

17. (from Web of Science Core Collection)

You searched for: **TOPIC:** (Bird) *AND* **TOPIC:** ("Wildlife trade")
Refined by: DOCUMENT TYPES: (REVIEW)
Timespan: All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.
Results: 4

18. (from Web of Science Core Collection)

You searched for: **TOPIC:** (Bird) *AND* **TOPIC:** ("Wildlife trade")
Timespan: All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.
Results: 67

19. (from Web of Science Core Collection)

You searched for: **TOPIC:** ("Wildlife trade")
Refined by: DOCUMENT TYPES: (REVIEW)
Timespan: All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.
Results: 29

20. (from Web of Science Core Collection)

You searched for: **TOPIC:** (ornamental) *AND* **TOPIC:** (plants) *AND* **TOPIC:** (animals)
Refined by: DOCUMENT TYPES: (REVIEW)
Timespan: All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC
Results: 19

21. (from Web of Science Core Collection)

You searched for: **TOPIC:** (ornamental plants, animals) *AND* **TOPIC:** (trade)
Timespan: All years. **Indexes:** SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.
Results: 30

14. NCP 14: MEDICINES and GENETIC RESOURCES

Lead Author: Yildiz Aumeeruddy-Thomas
Contributing Authors: Steve Polasky, Evelyne Strombom, Aidin Niamir and Kate Brauman

Key messages. Status and trends

1. Natural Medicinal Products (NMPs) constitute one of the most common human use of biodiversity (species and related habitats) that contributes significantly to human well-being

2. Increasing demands for NMPs by developed and emerging countries including for cosmetics and netraceuticals and industrialization of the production of traditional medicinal products, threatens biodiversity in developing countries where large proportions of the population rely heavily on NMPs for health care both for cultural reasons and because of limited access to conventional medicines.

3. IPLCs are recognized (strong evidence) to be the major providers of primary knowledge for the use of natural medicinal products but threats to IPLCs lifestyles, potential loss of ILK and global rate of loss of biodiversity forecloses opportunities for using such knowledge locally, and also for the development of new pharmaceutical drugs or formularized herbal preparations.

4. Modern new drug and equitable provision of health care to all societies for all diseases at the global level still depends heavily on NMPs as leads as opposed to purely synthetic drugs. Molecules invented by nature are more efficient than any molecules that human's could every dream to design.

5. ILK traditional medicines and modern drugs are highly contrasted in that the former is a common property and the second a private property, both relying strongly on nature. This raises major debates of equitability of Nature's contributions to people for health care at the global level.

6. Status and trends of this NCP is decreasing due to over-harvesting, loss of biodiversity, low recognition of customary lands of IPLCs and consequent decrease in capacity to identify NMPS. Final contrubutions are increasing in towns as urba dweellers increase their use of herbal medicines. Increasing recognition of ILK and ground level resilience movements, agroecology and biodiversity-rich agroecosystem at the global level as well as refined technologies for identifying new drugs may buffer the heavy decrease in potential.

14.1. IPBES Definition: IPBES Definition:

14 a Production of materials derived from organisms (plants, animals, fungi, microbes) used for medicinal and veterinary purposes
14 b. Production of genes and genetic information used for plant and animal breeding and biotechnology

14.2. Why is this NCP important?

14.2.1. What are the big environmental issues this pertains to?

Note: Environmental in the case of Medicinal and Veterinary uses of nature, should be ***socio-environmental*** *because of the intricate linkages between the two and the joint productionnature of this NCP*

NCP 14 a: Tens of thousands of medicinal plants are used and this usage may constitute the most common human use of biodiversity that contributes significantly to human well-being (Hamilton 2004, Schippmann et al. 2006, Leaman 2015, R.B.G. KEW 2017). Furthermore, food items across all societies are also important aspects of health systems, an idea which is alive in Oriental, Chinese, Japanese, Ayurvedic, Unani (Pakistan) medicines as well as in the Mediterranean region with the well-known Mediterranean diet (Zimmerman 2011, Mediterra 2012). With overall homogenizations of diet trends at the global level (see NCP 12), the link between food and NMPs is likely to become increasingly important, as shown by the increased use of nutraceuticals at the global level (Dillard and German 2000). The global market of nutraceuticals, includes functional foods, dietary supplements, and herbal/natural products, is estimated at USD 117 billion (Ansari et al. 2013).

The major socio-environmental issues are:

1) Biodiversity loss due to overharvesting, poaching for industry and/or long-distance markets, loss of habitats related to agriculture and urban expansion and other infrastructures, natural disasters and climate change

2) A major threat to 60 -80 % of the world's population relying on NMPs for their health (WHO 2013)

3) Loss of ILK developed by IPLCs, the latter being the major providers of primary knowledge for the use of natural medicinal products. This loss further forecloses the use of this knowledge as leads to identify new drugs.

NCP 14b. Genetic resources relate to all resources available in Nature that are used in agriculture, medicine or any other sector where genetic resources are managed for augmenting good quality of life. For example, genetic resources are most important for providing the world with food and feed (see NCP 14). At present just 3 crop species (wheat, rice and maize) represent 48 % of average daily calories consumed. Genebanks around the world hold some 3.6 million crop accessions half from 9 major crop species. Thus it seems obvious, that present genetic resources are highly under used in agriculture Genetic resources also relate to natural medicinal products. The range of genetic diversity within farmed animals and plants declines with production intensification. A relatively small number of animal and plantspecies provide the bulk of food production globally, and within these a high proportion of individuals have a relatively narrow range of genetic diversity. Commercial breeding tends to focus on a few species, which then has a tendency to lead to reduction in local genetic diversity. This is compounded by that fact that for developing countries it is often cheaper to import genetic material from the North. In order to counter this reduction in genetic diversity, countries would need their own breeding (Trondheim conference 2016).

14.2.1.1. Biodiversity loss and consequent loss of NMPs and genetic resources

Natural medicinal products (NMPs) 14a:: Biodiversity loss is a global phenomenon (Dirzo and Raven 2003) driven mainly by habitat destructions. NMPs are threatened more specifically by over-harvesting and poaching of specific species for an expanding market at local, regional and international levels, driven by increasing demands for natural resources by urban dwellers in developed countries and increased rates of human dwellers also in developing countries. Increasing volumes are harvested and largely from wild populations (Cunningham 1993, Kuipers 1997; Lange 1998, 2002, Schippmann et al. 2002,Lange & Schippmann 1997, Richerzhagen 2010, Wolff et al. 2017, Ahmad 1998 Schippmann et al 2002).

The use of herbal remedies is increasing worldwide, as governments and health practitioners integrate traditional medicine and other complementary and alternative practices, based on a growing scientific capacity to evaluate the medicinal properties, safety, and efficacy of these medicines. Research and development is increasingly lead by researchers and universities in addition to the pharmaceutical industry (Cunningham 1993, Schippmann et al 2002, 2006, Hamilton 2004, Richerzhagen 2010, WHO 2013, Leaman 2015). Undergoing industrialization processes to produce remedies used by scholarly medical systems such as the Tibetan, Chinese or Ayurveda (Kloos 2016, Pordié and Hardon 2015) or by local ethnomedical systems produce thousands of tons of industrialized traditional medicines, that are sold at the global level. The demand is thus growing for what is known as botanical medicines, producing large amounts of herbal teas but also nutraceuticals, cosmetics, personal care, all of which rely heavily on TNMPs[2] (Schippmann et al. 2002, 2006, Hamilton 2004). A major social consequence of long distance trade is the decrease of their availability to local societies and subsequent impacts on health especially in developing countries where people have little access to conventional medicine (Cunningham 1993, Lama et al. 2000, Hamilton 2004, WHO 2013, Wolff et al. 2017). Their trade in many cases may improve local economies which are however very vulnerable.

Overall biodiversity loss and habitat loss also directly affect availability of NMPs. Out of 72 000 traditionally known medicinal plants globally, a study made by the IUCN Medicinal Plants Specialist Group (based on Bramwells' 2003 assessment), it is estimated that 15 000 species are threatened (Schippmann et al 2006).

Effects of harvesting practices on medicinal plants also vary according vulnerability of species, linked to traits such as reproduction strategies, parts collected and harvesting practices of user groups (Schippmann et al 2002, 2006, Ghimire et al 2004, 2006, 2008). Natural disasters also lead to biodiversity loss and TNMPs (Joshi et al. 2011). Threatened traditional agroecosystems and associated ILK (e.g. shifting cultivation, Heinimann et al 2017) containing a large array of medicinal plants, is a threat to NMPs. Animal medicinal products are less known and in general less studied. In China, they represent 13% of the medicinal products used. Many species are threatened due to extensive and illegal trade, the most well known cases being tigers, rhinos, elephants, bears etc. (Still 2003). Many animals used as medicinals in China are listed as CITES species (CITES, 2002, Still 2003). In the Indian Himalayan Uttarakhand state, 39 animals are used for medicinal purposes with 20 species (51.3 %) that are listed in IUCN Red Data List (Negi and Khandari 2017). Although no global study exists, the status of emblematic species such as the Rhinoceros shows that between 1970 and 1987, 85% of the world's rhinoceros population was killed (Still, 2003). Less well-known animal populations used as medicine are also affected by land use changes, including industrial agriculture, use of polluting chemical products, deforestation, coral reefs destruction, climate change (Richerzhagen, 2010). Gaps in knowledge on zootherapy and lack of scientific evaluations may also under-evaluate their effective medicinal roles for human well-being.

Genetic resources 14 b: Wild crop relatives as well as local landraces of crops and animals are globally threatened due to little recognition pertaining to non-industrial or commercial agricultural systems, by nations as well as global food market systems that favor only a few crops (Tropenheim Conference 2016). Most crops and animal landraces have been identified by small farmers, fishers and pastoralists (that we integrate in the category of IPLCs), and the use of non-scientific knowledge, that we qualify as Indigenous and Local knowledge (ILK). The use of these crops and animal domesticates as genetic resources to produce new crops or transgenic resources such as GMO, at the global level is under the control of large firms which generally concentrate the production of medicines and seeds for agriculture and horticulture (Richerzhazen 2011). Thus production of new crops and animal landraces at the global level obeys to a major value i.e. industrial production, which leads to the impoverishment of global genetic resources in agrodiversity including their wild relatives (Castaneda et al 2015).

14.2.1.2. Threats to ILK, NMPs' related knowledge and genetic resources.

Most of the original knowledge related to NMPs has derived from long term connectedness between IPLCs and their natural environment (Schultes and Reis 1995, Efferth and Greten 2012, R.B.G. KEW 2017). Current threats and effective loss of ILK is a complex issue that requires quantitative approaches (Reyes Garcia et al. 2007, Furusawa 2009) and has been assessed at the

[2] We use TNMPs for Traditional Natural Medicinal Products and NMPs for any natural medical substance indifferently i.e. that may be originally used by traditional medicines and or identified by industry.

global level (Aswani et al. 2018). Transgenerational transmission of ILK which is mainly oral and linked to a large diversity of local languages is also threatened due to changes in lifestyles (Maffi 2001, 2005). These threats forclose opportunities for using such knowledge locally, and also for the development of new pharmaceutical drugs or formularized herbal preparations (Hamilton and Aumeeruddy-Thomas 2014). There is a general consensus however that ILK is highly adaptive and keeps on integrating new knowledge even in degraded lands or regarding invasive species (Benett and Prance 2000, Brandt et al 2013) which allows new NMPs to be discovered. ILK is also adapting to new diseases such as Aids and complementary approaches between modern and traditional medicines are being undertaken (Hamilton and Aumeeruddy-Thomas 2014).

14.2.2. How does NCP 14a play a role?

The production of materials derived from organisms (plants, animals, fungi, microbes) used for medicinal and veterinary purposes are of utmost importance for all human societies (MEA 2005).These products represent full organisms, portions of these, or genetic resources including genetic information, all of which are contained in the concept of biodiversity (Richerzhagen, 2010). Natural Medicinal Products (**NMPs**) contribute significantly to: (1) peoples' health and in doing so to all spheres of livelihoods including education, development of techniques and all aspects of well-being; (2) local and global economies; (3) and cultural development, medical systems being a set of culture associated to a range of relational values.

14.2.2.1. Health and Economy

In addition to modern drugs originating from natural products, it is estimated that 70–80% of people worldwide rely chiefly on traditional, largely herbal medicine to meet their primary healthcare needs (Farnsworth and Soejarto 1991; Pei 2001, Hamilton 2004, WHO 2013). The origin of modern drugs is linked to the discovery of antibacterial filtrate "penicillin" a natural microbe, by Fleming in 1928, and commercialization of synthetic penicillin which revolutionized drug discovery research giving way to important antibiotics such as streptomycin, chloramphenicol, chlortetracycline, cephalosporin C , erythromycin and vancomycin, original findings that have saved millions of people's lives (Butler 2004). Early modern drugs developed were based on leads from TNMPs in the 1950s and have led to the development of major drugs such as aspirin, digitoxin, morphine, quinine, and pilocarpine (Butler 2004, Efferth and Greten 2012). Natural products or related substances accounted for 40 % of the top 35 worldwide prescription drug sales in 2000, a figure that ranged between 24% in 2001 and 26% in 2002 (Butler 2004). 84 of a representative sample of 150 prescription drugs in the US fell into the category of natural products and related drugs. Newman and Cragg's (2012) latest update show a very large proportion of drugs (50 %) that are either derived directly from NMPs or chemically mimic active principles from the latter.

Derived drugs from traditional natural products contribute significantly to the profitability of many companies. The ratio to find a drug through screening traditional NMPs is one to thirty thousand or forty thousand. However, the potential profits are remarkable. In 1997, seventy-one drugs earned more than US$500 million each and twenty-seven blockbuster drugs earned more than US$1 billion each per year. Estimates for the pharmaceutical sector indicate the increasingly significant role of natural resources in the development of pharmaceuticals even though less new natural products are used. Today more than half of the drugs in the market are natural products or derived from natural products. It has been estimated that the pharmaceutical industry earns about US$32 billion a year in profits from products derived from traditional remedies (Harrison and Pearce 2001). In China alone, the market value of Chinese *Materia Medica* was estimated to be US$83.1 billion in 2013 (World Health Organization *2013*). The total sales' value of drugs (such as Taxol) derived from just one plant species (*Taxus baccata*) was US$ 2.3 billion in 2000 (Laird and ten Kate 2002). The world market for herbal remedies in 1999 was calculated to be worth US$ 19.4 billion, with Europe in the lead (US$ 6.7 billion), followed by Asia (US$ 5.1 billion), North America (US$ 4.0

billion), Japan (US$ 2.2 billion), and then the rest of the world (US$ 1.4 billion) (Laird and Pierce 2002)". In 2003, the World Health Organisation (2003, 2014) estimated the annual global market for herbal medicines to be worth US$60 billion and by 2012 the global industry in TCM alone was reported to be worth US$83 billion.

Incentives for private companies to invest in bioprospecting depend on anticipated future returns and risks (Sarr et al. 2008), including effect of technological developments and search efficiency/distribution of leads. Likelihood of success is highly dependent on knowledge of local conditions, for example, secondary forests are estimated to be richer in medicinal plants than mature forests and landscapes with forests of different ages likely to hold more potential (Gavin 2009, Leaman 2016). Amounts of information already collected in the large gene banks that are now available from nature-based products is probably sufficient to continue synthesizing new drugs. Efforts can now indeed be based on genetic and chemical information rather than screening new natural material (Moretti and Aubertin 2007).Combinatorial chemistry libraries are more successful than natural product drug discovery in further developing or optimizing the process from hits of screens to leads and to approved drugs (Richerzhagen, 2010). Discovery that are based strictly on chemical approaches that do not use natural leads and development of de novo combinatorial compounds leading to an approved drug are very few and the industry still relies on natural products for new drug discovery. Moreover, this method has become less difficult to use thanks to technological advances (e.g., separation technologies, speed and sensitivity of structure elucidation (Newman, Cragg, and Snader 2003).In 2004 the pharmaceutical market topped US$500 billion (Richerzhagen 2010). This is a 7 percent increase over 2003 and a 28 percent increase compared to 2001.

Although pharmaceutical companies show less interest for bioprospecting, it is acknowledged that research organizations (universities and other institutions) are increasingly engaged in screening and testing the effects of active principles of NMPs (Efferth and Greten 2012, Richerzhazen 2010). There is an increase of patents developed by the latter over the past decade as well as by universities in developing countries engaged to find new formulations for widespread regional diseases (Tittikpina et al. 2016)

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14.2.2.2. Cultural development and relational values

From a cultural perspective, NMPs constitute the pharmacopeia of a large diversity of medical systems including scholarly systems such as Ayurvedic, Chinese, Japanese Kampo, Pakistani Unani, Tibetan, European and Arab medical systems, based on written sources and a large diversity of regionally shared or local folk medical systems based on oral traditions (Pei 2001, Hamilton 2004). Ayurvedic and Chinese medicine, alone represent billions of daily users. In all biomes, local societies rely largely on orally transmitted medical systems that link people to nature and non-tangible elements of nature (Fleurentin 2008, Schultes et al 2001, Zimmerman 2011). Shamanistic systems are widespread in South- America and in Central Asia with variations in diverse parts of the world. This diversity of medical systems stems from nature-culture ontologies embedded in diverse conceptualizations of nature that link people to nature and health on the basis of different concepts of the body, its functioning in connection with natural and supra-natural elements, including direct contact with nature (Levi Staruss 1966, Descola 2013, Cuerrier et al. 2015).

Small-scale agricultural farmers and other non-industrial user groups, mostly IPLCs rely almost entirely on natural products from their immediate environment for their health (Hamilton & Aumeeruddy-Thomas 2014, Leamen 2015) and on local genetic resources in the form of traditional crop and animal landraces for food (Gollin and Everson 2003, Tropenheim Conference 2016). These resources are an entire part of common property lands and biocultural landscapes which are shared following customary rules. While these resources are locally used, they can also betraded. Deep relational linkages link IPLCs wth resources as it is demonstrated that displacement from lands and resources may lead to major physical and mental health problem (e.g. Incayawar 2009). At the opposite, industrial production of improved crops, and medicines that are fully under private properties.

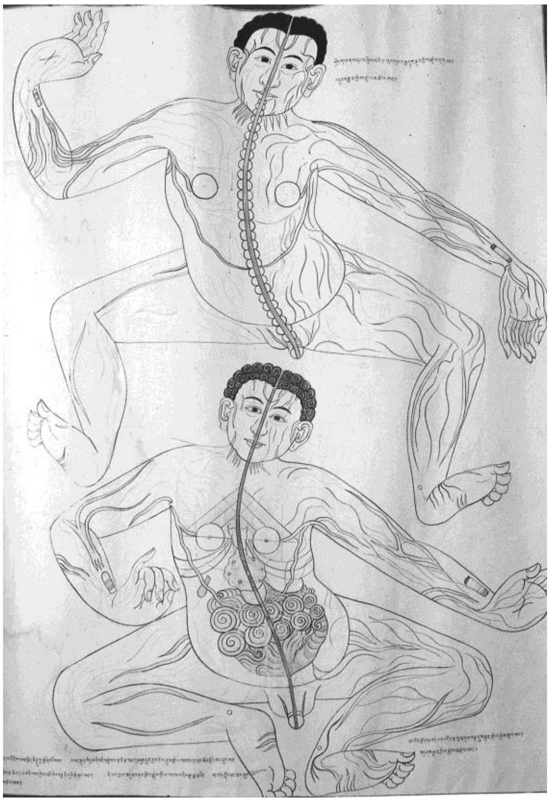
14.3. (Co-) production

14.3.1. How is this NCP produced and co-produced?

Human's capacity to identify natural products and transform them into Natural Medicinal Products (NMPs) depends on people's capacity to identify the right species, their level of efficiency for specific illnesses,availability and quality including types of active principles (alcaloïds, terpenes, organic volatile components etc.) and right formulations and preparations for its administration to patients. Active components used by plants or animals either to protect themselves from predators or to attract pollinators (plants) or send signals for mating or to mark a territory (e.g. deer musk) are generally the active principles for medicine. These principles also known as secondary metabolites are the result of long evolutionary processes involving mutualisms or eviction mechanisms between species (Efferth and Greten 2012). This NCP emerges from the encounter of these "gifts" from nature and observation and exploration by humans of their capacity to heal specific diseases including through observing animals.

There are two major approaches in co-production of NCPs:

(1) co-production by ILK within natural and co-constructed landscapes and agroecosystems (2) co-production by modern chemical and genetic analytical approaches of NMPs from nature and co-constructed landscapes. The gradient between the two approaches of the amount of nature decreases dramatically from (1) to (2), especially when the second approach uses molecules that mimic nature.ILK generally rarely isolates a unique secondary metabolite, but rather uses whole parts of plants or animals that contain a vast array of active principles. It has been argued by traditional healers that synergies within the whole plant is important; the natural "energy" of the plant is an aspect little understood by science but highly developed in scholarly medicines such as the Tibetan Sowa Rigpa or in ancient European folk medicines (Thèvenin 2013, Fleurentin 2008, Khangkar Dolkar 1999).



« Le canal psychique au centre connecte les cinq points d'énergie principaux, partant du sommet du crâne, finissant aux parties génitales. Les cinq régions en lesquelles le corps est divisé dans la médecine tibétaine, correspondent aux cinq familles de Bouddha (jina). Chaque jina correspond à des types particuliers d'énergie. […]. C'est dans ces régions que le médecin tibétain recherche manuellement les tensions spécifique » Translation Y-A-Thomas : The psychic canal at the center connects the 5 principal energy points, starting from the top of the skull, finishing in the genital parts. The five regions into which the body is divided in tibetan medicine correspond to five families of the Buddha (*jina*). Each *jina* corresponds to particular types of energy […]. It is in these regions that the tibetan doctor manually looks for specific tensions »
Médecine Tibétaine, La Méthode Bouddhiste de Guérison, Khangkar Dolkar (1999)

ILK uses natural products from resources found locally within customary territories generally under common property rights or exchanged within relatively short distance markets; knowledge is held by specialists but part of this knowledge generally pertaining to non-toxic species, is shared by all community members. Strong levels of relational values (social and psychological) underly all healing practices. Validation of the efficiency is informal and based on historical transmission of knowledge and empirical experience within biocultural landscape and customary lands, although in all scholarly systems such as Chinese medical systems formal internal systems of validation exists. Genetic resources relating to crops are also shared resources although individuals may show great expertise and manipulate many more resources than others. IPLC's institutions relating to genetic resources are based on local to regional social seed exchange networks (Coomes et al. 2015)

Modern drugs are developed by pharmaceutical industries that use sophisticated chemical, genetic and computational methods that use plants, animal and fungi ex situ. They generally tend to isolate single active principles, synthetize new molecules that mimic the latter; processes arepatented and this knowledge and all resources derived from it are a privately owned, and driven by economic values (Newman and Cragg 2012). Validation of a drug is done through blind medical trials and national level acceptance of each drug is required. Application of the use of this knowledge is under the control of medical doctors and national agencies with a small proportion of drugs that can be used without prescription. Side effects of many modern drugs are well known but their efficiency is also highly proved. Crop genetic resources developed by modern crop improvement techniques is generally the property of industries and sometimes research institutions that have contributed to develop the varieties. They are sold on markets and national or international level regulations mays limit their reproduction by local farmers.

Thus ILK traditional medicines and modern drugs are highly contrasted in that the former is a common property and the second a private property, both however relying strongly on nature, which raises ethical debates (Richerzhagen 2010).

14.3.1.1. IPLCs and their role in the co-production of NMPs

A vast amount of published literature, books essays, papers covering all continents, and almost all cultural groups known to date show that historical and contemporaneous connectedness between Indigenous Peoples and Local Communities (IPLCs) with nature, anthropogenic landscapes and complex traditional agroecosystems, are at the origin of the majority of discoveries of traditional pharmacopeia (Schultes and von Reis 1995, Fleurentin 2008, Zimmerman 2011, Bussman and Sharon 2015, Leaman 2015), as well as regarding agricultural genetic resources including in the shaping of anthropogenic landscapes that are niches that host the diversity of resources that are used (see sub-chapter nature). IPLCs including small-scale farmers and fishing communities have a holistic knowledge approach (Tengö et al 2017, IPBES regional reports) that incorporates a large diversity of modes of interactions between all species, humans and the intangible nature of species (Levi Strauss 1966, Ingold 2000, Atran 2002, Descola 2013). ILK analyses simultaneously, the function and qualities of the finest nature of all things (e.g. the grain of the wood, the taste of the spice, the toxicity of the wing of an insect or of the skin of a frog). It also analyses how it can best improve the health of other species, ecosystems, soils and the lives of humans all together. This knowledge is based on constant and long-term observations and learning (see NCP 15). IPLCs' connectedness with nature (see Box 1 in Appendix 1, below) form the base for understanding the complex nature of NMPs. Food, NMPs and ecology are often associated in ILK linking diets and healthcare (e.g. Zimmerman 2011)

Health of IPLCs based on ILK are tightly connected with the sense of place and lack of access to biocultural landscapes which provide foods and medicines, often more qualitatively adequate than in areas where they are dislocated (Cuerrier et al 2015). Lack of recognition of traditional medical practices at national levels such as Tibetan medicine in Nepal, Lama et al 2001 or folk medicine in France (Sauvegrain and Aumeeruddy-Thomas 2006, Thèvenin 2013), also lead to lack of continuity in the transmission of ILK regarding NMPs and eventually loss. Diverse revitalization program are however developing at local, national and regional levels such as the FLRHT in India http://www.frlht.org/, Himalayan Amchi Association in Nepal, http://www.drokpa.org/doc/Himalayan_Amchi_Association.pdf, Uganda (Hamilton and Aumeeruddy-Thomas 2004)

14.3.1.2. Modern Drug development

Modern drugs either use leads from traditional NMPs or blind screening of natural products haphazardly collected that involve long, highly sophisticated and expensive processes (Butler 2004, Efferth and Greter 2011, Newman and Cragg 2012). Although new drug discoveries may come from recombination of molecules and chemical engineering, , natural products with evidences from traditional medicines or which are phylogenetically associated to the latter (close species, same families) are still the best option to find totally new conventional drugs (Newman and Cragg 2012).This is exemplified by undergoing pharmaceutical research on fungi (the least advanced in this field). Fungi species have been utilized in Asia for millennia (China, Japan and South East Asia) and are still traditionally used against tumors and as general reinforcing nutriments for long life. Fungi are also used as psychoactive products throughout the planet by all human civilizations including northern Europe (Wasson 1979) with the aim of changing levels of consciousness, often within the context of religious rituals such as the use of Soma the pan-asiatic fungi used by pre-Vedhic, Vedhic and Buddhists priest (Dannaway 2009). Biochemical research on higher fungi, prove to have important impacts on many diseases including cancer, immunological and possibly neurodegenerative diseases. One of the hypotheses regarding the latter is that their bioactive principals are made of the smallest active molecules on earth or ever found which are likely to pass the brains highly protective barriers (Pourcheret et al 2006).

Bioprospecting is the search for natural materials and associated knowledge with potential commercial value. Pharmaceutical use commonly drives interest in bioprospecting. Other applications include enhancement of crop production and industrial fermentation, and development of bioinspired materials and design. Adoption of traditional knowledge of land, landuse, and landraces also falls under this definition. In addition to commercial interests, some have argued that bioprospecting can be a mechanism for development (Artuso 2002) as well as for biodiversity conservation. The Nagoya Protocol (2010) provides a legal framework for the implementation of one of the three objectives of the Convention on Biological Diversity (CBD): the fair and equitable sharing of benefits arising out of the utilization of genetic resources. The Nagoya Protocol entered into force in 2014. The Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) under the World Trade Organization also protects bioprospecting rights; however, notably it lacks mechanisms for dealing with collectively held intellectual property, including traditional knowledge. Major concerns exist about bioprospecting and whether it is fundamentally unequitable and exploitative of IPLCs. Bioprospecting raises ethical issues of access and benefit sharing (ABS) (Cunningham 1993, Richerzhagen 2010). Critics claim that profits from commercially developed drugs go to pharmaceutical companies without benefiting groups whose traditional knowledge may have been instrumental in developing the drugs (Richerzhagen, 2010, Drahos 2014). Commercially developed seeds of improved crops and animal races based initially on local crops and landraces also raises similar issues. This situation is particularly troubling in cases where IPLCs suffer from inadequate access to conventional health care or face food scarcity or dietary problems. Concerns over access and benefits sharing have led some critics to claim that bioprospecting is really biopiracy or bioimperialism (Davalos et al. 2003, Day-Rubenstein and Frisvold 2001, Richerzhagen 2010, 2011, Greene 2004, Nigh 2002). It was hoped that bioprospecting would drive private or market-oriented conservation. However, early commercial initiatives were unsuccessful and have not generated the conservation and development outcomes that were anticipated (Firn 2003, Costello and Ward 2006, Day- Rubenstein and Frisvold 2001). Goeshl and Swanson (2002) argue that private valuation of research and development underestimates the social value of genetic resources.

The main technologies used for drug development are screening of libraries for synthetic compounds and natural products and rational drug design based on genomics (Richerzhagen,2010). Free access of samples from large herbarium, the latter in some cases funded by large bioprospecting companies, as well as large amounts of published ethnobotanical literature that fall under the public domain provide a large set of information including genetic information.

Though there has been debate, estimates of potential returns are largely considered too low (under $300/ha) to attract large-scale, private-sector interest (Costello and Ward 2006). In accordance, agrochemical and pharmaceutical companies seem to devote a scant amount of their R & D budget to bioprospecting, if any at all. Merck & Co.'s prominent $5 million venture with Costa Rica's National Biodiversity Institute (INBio) yielded no major discoveries in roughly 15 years, and in 2008 they stopped searching for natural compounds in favor of synthetic products and vaccines. Most big pharmaceutical companies have now ceased investments in bioprospecting (UW Conservation Magazine). Ramesha et al. (2011) reports a "perceptible" decline in the discovery of novel bioactive compounds. Overall industrial secrecy related to patenting approaches do not allow to effectively evaluate the situation.

***Summary of how this NCP is produced*:**

- **1. Direct**: Historical connectedness between ILPCs and resources and a continuing access to lands that allow practices and conceptualizations of nature that facilitates identification of NMPs and their use locally
- **2. Direct**: Chemical screening of traditional NMPs or random samplings, analyzing active compounds and gene level information and synthesizing artificial drugs

14.3.2. How is (co)production of this NCP measured?

All biomes and all plants, animal and fungi diversity can potentially reveal molecules that could be used as medicine or for food and feed. Toxic species can also be used providing humans identify detoxifying technologies, many examples of which are known for medicinal plants and fewer, for food. In that respect, biodiversity richness at the global level represents the potential for identifying medicine and agrodiversity. Indigenous and local, or scientific knowledge have complementary approaches and are needed to identify appropriate species and design good formulations and preparations (often with other species, or molecules) and test them for medicine or select new varieties according to environmental and human requirements. Thus potential for obtaining medicines or agrodiversity for food is a joint production implying nature availability and human assets. Cues regarding what is already known, such as plant families that have specific compounds, or dietary traits are an important approachto identify potential food or other genetic resources. Below we use medicinal plants richness and vascular plant richness as a proxy to discuss global potential for new discoveries in medicinal plants, but also animals and fungi. It is indeed expected that vascular plant richness correlates to some extent with non-plant taxa (e.g. animal) (Kier et al. 2009) eventhough such correlations are not always valid especially in marine ecosystems (see sub-chapter Nature). It is likely that terrestrial animal and fungi medicinal diversity are also high in the highest areas of plant diversity, an assumption that has been used in hotspot approaches (Myers et al 2000) and tested regarding island diversity (Kier et al 2009). Tropical forests, which represent the biome with the highest level of biodiversity is known to yield also the highest diversity of medicinal plants (Hamilton 2004).

The potential of nature's contributions to provision of medicinal plants (important for a large proportion of the global population (60-80 %), that still relies almost entirely on natural medicinal products), can be represented by a Map of the distribution of medicinal species known to date overlaying overall plant richness distribution (IPBES, Core) (Figure 5, below) . This series of maps uses data generated by R.B.G. KEW of medicinal plants richness, which botanical identity is established, and overall vascular plants richness (Kreft and Jetz 2007). The potential of nature is represented by plant natural richness, but the co-production of this NCP is linked to places where human groups have the capacity to identify medicines based on different types of knowledge (ILK, Science) and also have access to biodiversity, which we have represented by the 3rd map of the series, which is a normalized distribution of medicinal plant richness by vascular plant richness (IPBES Core) . The capacity of plants that are phylogenetically close, have a higher probability to have similar secondary compounds and are distributed in similar ecosystems (e.g. plants from the Annonacea family are all in South American Tropical Forests) and it has also been shown that people choose plants that are directly available in their environment. This augments their likelihood to be identified locally (a system also currently used by pharmaceutical industries to screen unknown species), especially in areas where environmental conditions favor development of secondary compounds (Saslis-Lagoudakis et al. 2012, 2014). The medicinal plant richness normalized by vascular plant richness is thus an indicator of potential levels, across biomes and ecosystems of NCP Medicine.

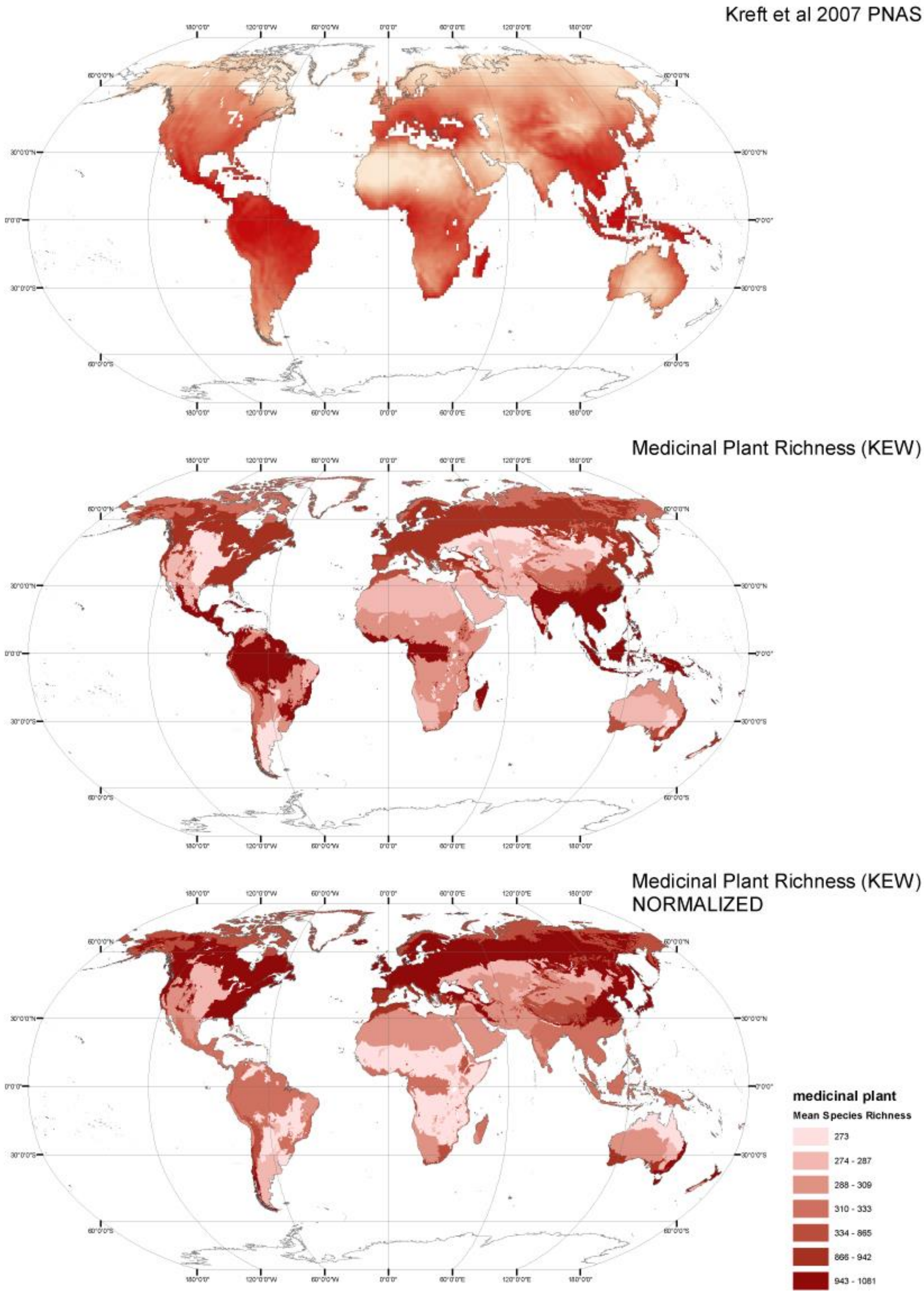


Figure 5 : The 1st map in this series distribution oftotal plant richness based ondata from Kreft & Jetz 2007, the 2nd map shows medicinal plants richness based on data from RBG KEW (Pironon et al. in review), the 3rd map illustrates the richness of medicinal plants normalized by vascular plant richness

Chemical analysis of plants cover only 15% of known plants (Efferth and Greten 2012) while TNMPs t represent 17,1 % of total plant species (Schippmann et al 2006). This average of 15-17% of known medicinal plant species is a conservative one and can also be used as a proxy for what is known to date for plants i.e. the realized NCP which is not representative of potential future findings. ILK is known to be in a process of constant search for alternative species including the use of invasive and newly introduced species in many places (Efferth & Greten 2012), so changes in habitats does not mean automatically loss in richness of medicinal plants used. Secondary tropical forests are for instance known to have a high richness in medicinal species and open pasture lands in Europe linked to traditional pasture management are also known to host a high richness f medicinal species (Lange 1998). Although medicinal plants are mainly wild- collected for reasons that have been analyzed (Schippmann et al 2002, 2006), many wild medicinal plant species are also found in anthropologic landscapes and multifunctional traditional agroecosystems, because they are favored by ILK. This is not the case in industrial agricultural areas.

Traditional anthropogenic landscapes such as cultural landscapes in Europe including Mediterranean Dehesa and Montades Woodlands or similar formations in Northern Africa (Gallardo et al 2016, Garcia-Tejero and Taboada 2016), tropical, sub-tropical and Mediterranean agroforestry systems and home gardens, found at the global level and across all continents are known to host a large diversity of medicinal plants often deliberately protected by IPLCs or planted in home-gardens (Genin et al 2013, Michon 2005, Michon 2015, Michon et al 2000, 2007, Eyzaguirre and Linares 2004). A map of agroforestry systems around the world shows the extent of such systems (Figure 6: MAP 2, Zomer et al 2009). These areas are places where medicinal plants species are under trials for domestication by ILPCs and or with the help of external projects.(e.g. Prunus Africana, Simons and Leakey 2004). The distribution of complex high –biodiversity agroecosystems are also one indicator of co-production of NMPs.

Tree Cover on Agricultural Land - Global

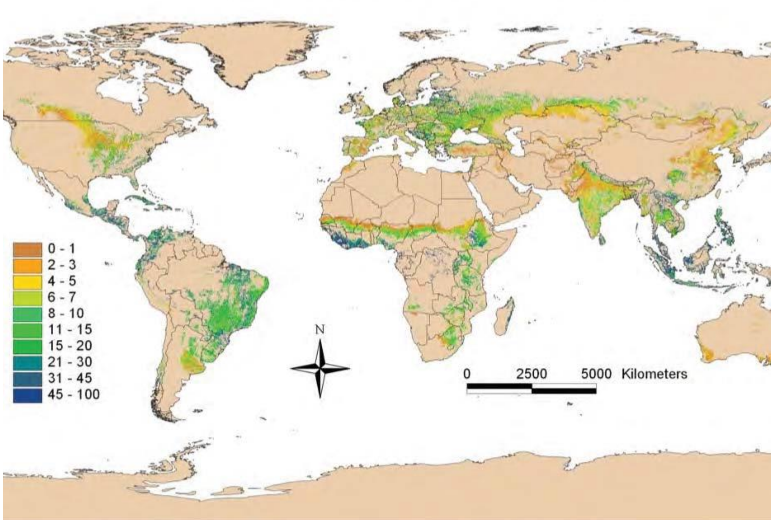


Figure 6 : Map 2: Source Zomer et al. 2009, http://www.worldagroforestry.org/downloads/Publications/PDFS/WP16263.pdf

14.3.2.1. New drugs derived from NMPs, a proxy for co-production by scientific methods

Assessment of drug development over 30 years in relation to all diseases known at worldwide level since 1981 and since 1950 for antitumoral drugs identify drugs as, Natural, Natural Botanics, Natural products Mimic and Synthetic (Newman and Gragg 2012). They show that in the area of cancer, over the time frame from around the 1940s to 2012, of the 175 small molecules, 131, or 74.8%, are other than "S" (synthetic), with 85, or 48.6%, actually being either natural products or directly derived therefrom. The anti-infective area is also highly dependent on natural products and their structures. There is a rapidly evolving recognition that a significant number of natural product drugs/leads are actually produced by microbes and/or microbial interactions with the "host from whence it was isolated" (Newman and Cragg 2012). These authors confirm that althoughthe development of high-throughput screens based on molecular targets had led to a demand for the generation of large libraries of compounds, the shift away from large combinatorial libraries that was becoming obvious at that time has continued, with the emphasis now being on small focused (100 to ~3000 plus) collections that contain much of the "structural aspects" of natural products that they term as Natural Product Mimics. This extensive work repeatedly reviewed in 1997, 2003, 2007 and finally in 2012, regarding all diseases and all new drugs produced between 1980 to 2010, shows that the highest probability to find new drugs in the future shall be related to NMPs. They provide the following major comment "At the broader level, we note that this program will confirm once again (if further confirmation is, indeed, necessary) the extraordinary advantages of small molecule natural products as sources of agents, which interject themselves in a helpful way in various physiological processes." In this assessment, we use therefore as proxies for co-production of drugs by modern medicine based on NMPs or synthetized on the basis of NMPs structure (Natural Mimics), the % of the latter among all new drugs developed at the global level, that have been identified over the last 30 years.

14.3.3. Links to other NCPS

note specific links as appropriate, otherwise delete

Soils affect vegetation and are in turn affected by vegetation, so all NCPs have feedbacks to soils

NCP2 – pollination – Plants use volatile compounds to attract pollinators. These volatile compounds are among the active principles that may be used as active medicinal principles. Pollinators and their derived products such as honey represent a great potential for identifying new drugs
NCP3 – air quality – The quality of NMP is highly linked to air quality. Indeed any type of pollution in the air (heavy metal, radioactivity or other pollutants will affect the quality of natural medicinal product) and impact negatively human health.
NCP4 – climate – As any other component of biodiversity, Natural Medicinal Products will be very sensitive to Climate Change. Some species may be even more sensitive because there secondary compounds are highly sensitive either to ozone concentrations or temperature such as Volatile Organic Compounds (VOC)
NCP5 – ocean acidification – Algae and other known medicinal products from the sea are likely to be affected by ocean acidification
NCP6 – water quantity – Same as for air quality
NCP7 – water quality – Same as for air quality
NCP8 – soils – Same as for air quality. Furthermore active compounds in plants may be highly influenced in terms of content in relation to soil quality, one of the reasons why cultivated medicinal species are less appreciated than wild ones. Pesticides and chemical inputs are counterproductive for the production of NMPs
NCP9 – hazards – they affect all biomes and as such can affect the potential for NCP medicine and genetic resources, whether cultivated or wild.
NCP10 – pests – As any other element of biodiversity, NMPs may be subject to pest attacks, however due to their own very strong capacity to protect themselves against pests due to secondary compounds, many NMPs are used worldwide for pest management.
NCP11 – energy – None of what we know

NCP12 – food – NMPs have a very tight linkage to food as many food products in many cultures are meant to have positive impacts on health. Food preparations are however very different from medicines and Medicines and Food are complementary approaches to well-being.
NCP13 – materials – some medicinal may represent simultaneously materials especially for trees which have multipurposes depending on the parts collected.
NCP15 – learning – As shown above the co-production of knowledge, both from ILK science, the learning component is an entire part of the co-production process.
NCP16 – experiences – Same as above, in so far as we can effectively distinguish, what is learning from a strict intellectual perspective, from all physical experiences required to test any NMPs
NCP17 - identities –As also shown above the large diversity of medical systems are fully linked to cultural contexts, relational values and cultural identities.

14.3.4. Indicators of NCP (co-) production

Rationale and proxy used to assess trends and impacts on good quality of life

NCP	Production Function	Indicator/ Proxy	Rationale/ justification for why this indicator/ proxy was selected	Data set	Scale of Measure – space	Scale of measure - time
14 a	**Potential of Natural Medicinal Products**	MAP of Medicinal Plants overlaying plant richness at the global level.	This proxy represents global level distribution of presently known Medicinal Plant species overlaying overall plant richness. .	Data provided by R.B. G. KEW (Pironon et al. under review) and Vascular Plants Richness based on Kreft & Jetz 2007	Global	No trends of change available.
14 a	**Overall biodiversity richness**	Percentage of New drugs discovered over the last 30 years based on NMPs and or as mimics of NMP structures?	We chose this indicator because the data time series is long enough and that a series of revisions have been conducted by well recognized authors in that field with a series of publications and updated data, showed with the greatest rigor. The data by Newman and Cragg (2012) is further corroborated with data shown by other global level review studies on this subject.	*All data available in* Newman, D. , Cragg, G. , & Snader, K. (2003). Natural Products as sources of New Drugs over the Period 1981 - 2002. *Journal of Natural Products*, *66*(7), 1022–1037. https://doi.org/10.1021/np200906s. Natural Newman, D. J., & Cragg, G. M. (2012). Natural Products As Sources of New Drugs over the 30 Years from 1981 to 2010. *Journal of Natural Productws, Review*(75), 311–335. https://doi.org/335 dx.doi.org/10.1021/np200906s	Global	30 years from 1981 - 2010

				Butler, M. S. (2004). The role of natural product chemistry in drug discovery. *Journal of Natural Products*, *67*(12), 2141–2153. https://doi.org/10.1021/np040106y Richerzhagen, C. (2010). Protecting Biological Diversity. The effectiveness of access and benefit sharing regimes. London: Routeldge		

Summary of Potential NCP, Output of the co-production and impact on good quality of life of Natural Medicinal Products and genetic resources

	Potential Nature's Contributions	Output of co-production	Impact on good quality of life
INDICATOR	A) Biodiversity with high potential for having bioactive principles for medicines or represent genetic resources useful for medicines agriculture or other purposes, that have been identified locally through ILK or by other knowledge systems at global levels for health treatments or other purposes (agriculture or other). The proxy used: MAP Medicinal plants and overlap with global plant richness (Source IPBES Core, see Fig 5) B) Biodiversity richness at global level (Plants, Animals and Fungi, terrestrial and Marine) available/ Indicator: MAP of global biodiversity richness terrestrial and marine/ or Biodiversity Intactness Richness Index per Units of analysis (see subchapter Nature)	A) Medicinal plants known to date and accessible for health care as a proxy for all Natural Medicinal Products (NMPs). 70 000 species (cf. IUCN Medicinal Plants Specialist Groups of the Species Survival Commission Genetic resources and especially agrodiversity known to date and its linkage to food security (FAO 2010, Khoury et al. 2014) B) More than 25% of new chemical entities déveloped for drugs for all diseases treated at the global level over the last 30 years are derived from natural products or chemical leads from NMPs and more than 70% of drugs to treat cancers derive directly from NMPs (Newman & Cragg 2012)	**(A) Percentage of world population relying almost entirely on NMPs (Indicator 1)** More than 50 % of the world population relies exclusively on NMPS for their health (WHO 2013) (B) Percentage of modern drugs based on NMPs or bio-inspired molecules used for diseases at the global level. 20 % of modern drugs currently used for all diseases at the global and more than 70 % drugs used to treat cancer are based on NMPs (Newman et al. 2003, Newman & Cragg 2012).
Trend During the last 30 years:	(A): -2 decrease: Overall loss of biodiversity in all units of analysis at the global level + overall trend of loss of ILK including access to customary	(A): -2 decrease An estimated 21% of known medicinal plants i.e. 15 000 are threatened (Schippmann et al. 2006)	(A): -1 NMPs in rural areas are decreasig as an overall result of decrease in biodiversity with potential concomitant effects on more than 50% of the world's population that relies almost

2 = Major increase (>20%) 1 = Increase (5% to 20%) 0 = No change (-5% to 5%) -1 = Decrease (-20% to -5%) -2 = Major decrease (< -20%)	territories, reduces overall capacity to identify new drugs from nature, including from perturbated ecosystems or agroecosystems. (B) : - 1 decrease Loss of biodiversity compensated by anthropogenic assets i.e. improved capacity to identify drugs from NMPs (therefore counterbalaces the overall loss in potential)	(B): 1 increase A steady increase in drugs found based on natural products over a period of 30 years for all major diseases at the global level (Newman et al. 2003, Newman and Cragg 2012). Little explored biomes such as Oceans have revealed 30 000 new compounds over the last 50 years (Alves et al. 2018)	exclusively on NMPS for their health New urban users increasingly using a small proportion of NMPS but in very large amounts: globally (B): Increase in life expectancy globally.
Spatial variance 3 = opposite trends in different regions 2 = same directional trends in different regions but of contrasting magnitude 1 = similar trends all over the world	**(A) 3**. Units of analysis known to yield high levels of bioactive principles (e.g. tropical forests), units under great biotic stresses (e.g. high mountains, mediterranean shrublands etc.) are more threatened than urban areas or industrial agricultural áreas or units of analysis with little biodiversity or under little biotic stresses. **(B) 3** Potential for identifying new drugs from NMPs vary between developed and developing countries due to concentration of large enterprises exploring NMPs for drugs or agricultural purposes in a few rich countries (Richerzhagen 2010, 2011)	(A) 3 NCP 14 is decreasing in source areas in all units of analysis that produce NMPs due to overharvestig and other drivers (loss of biodiversity, changes in land use), but increasing in urban areas which import increasingly large amounts of NMPs (B) 3 NCP14 in the form of drugs base don NMPS are more accesible in developed countries as opposed to developing countries due to lack of access to converntional medicines in developing countries is well demonstrated, partly because of lack of conventional practiners, as well as high costs of medicines (Bodeker et al. 2005, Leaman 2015).	A): **3** (see above) There is a contrast between local users in source areas having less access to NMPS as opposed to distant users mainly located in towns having an increasing access through trade of NMPs (B):**3** People in rural areas, and mostly IPLC have little access to conventional medicines and people in towns have a better access although this may vary also among different sections of the population and across countries.
Variance across social groups 3 = opposite trends for different groups 2 = same directional trends for different groups but contrasting magnitudes 1 = similar trends for all social groups	**NA**	(A) 3 User groups living in proximity with nature have a greater capacity to co-produce NMPs and genetic resources, especially within high biodiversity anthrogenic landscapes than urban dwellers or communities managing low-biodiversity agricultural systems. IPLC territories with different forms of tenure rights and a diversity of management systems cover at least 28 per cent of global land area, including at least 40 per cent of the area that is formally protected, and some 37 per cent of all remaining terrestrial areas with very low human intervention (Garnette et al 2018). User groups living in more artificialized environments contribute less to joint production and management of NMPs and genetic resources.	**A) 3** Impact on good quality of life for people that still rely on NMPs found in there close environments in high biodiversity anthropogenic landscapes is high (WHO 2013). Diets of people globally and especially those living far from nature is decreasing (Khoury et al 2014) and extent to which NMPs improves their health is not demonstrated. **B) 3** People living in close proximity to nature (all small scale farmers, fishers, gatherers, pastoralistes etc.), especially in por countries, have

		Only very few industries in the world concentrate the production of the overall drug productions based on bioactive principles and improved genetic resources for industrial agriculture (Richerzhagen 2010, 2011)	little access to conventional drugs (WHO 2013, Leaman 2015). People from developed countries have a higher access to conventional drugs
Degree of certainty 4 = **Well established**: Robust quantity and quality of evidence & High level of agreement 3 = **Established but incomplete**: Low quantity and quality of evidence & High level of agreement 2 = **Unresolved**: Robust quantity and quality of evidence & Low level of agreement 1 = **Inconclusive**: Low quantity and quality of evidence & Low level of agreement	**(A) 3** **(B) 3**	**(A) 4** Many evidences are available showing importance of NMPS at local levels for health care (WH0 2013) and their availability at global levels (Richerzhagen 2010, Hamilton and Aumeeruddy-Thomas 2013). **(B) 4** Evidence available of capacity of science to deliver drugs that are efficient on most diseases at the global level, based on NMPS (Newman and Cragg 2012)	**(A) 3** **(B) 3**
The two most important papers supporting the reported trend	Schippmann U, Leaman D., Cunningham, A. B. (2006). Comparison of cultivation and wild collection of medicinal and aromatic plants under sustainability aspects. In D. L. R.J. Bogers, L.E. Craker, D. Lange (Ed.), *Medicinal and Aromatic Plants* (pp. 75–95). Newman, D. J., & Cragg, G. M. (2012). Natural Products As Sources of New Drugs over the 30 Years from 1981 to 2010. *Journal of Natural Productws*, *Review*(75), 311−335. https://doi.org/335 dx.doi.org/10.1021/np200906s	Schippmann U, Leaman D., Cunningham, A. B. (2006). Comparison of cultivation and wild collection of medicinal and aromatic plants under sustainability aspects. In D. L. R.J. Bogers, L.E. Craker, D. Lange (Ed.), *Medicinal and Aromatic Plants* (pp. 75–95). Newman, D. J., & Cragg, G. M. (2012). Natural Products As Sources of New Drugs over the 30 Years from 1981 to 2010. *Journal of Natural Productws*, *Review*(75), 311−335. https://doi.org/335 dx.doi.org/10.1021/np200906s Garnett, S. T., Burgess, N. D., Fa, J. E., Fernández-Llamazares, Á., Molnár, Z., Robinson, C. J., … Leiper, I. (2018). A spatial overview of the global importance of Indigenous lands for conservation. *Nature*	Wolff, S., Schulp, C. J. E., Kastner, T., & Verburg, P. H. (2017). Quantifying Spatial Variation in Ecosystem Services Demand: A Global Mapping Approach. Ecological Economics, 136, 14–29. https://doi.org/10.1016/j.ecolecon.2017.02.005 Leaman D. (2015). Traditional Medicine. In *Connecting Global Priorities: Biodiversity and Human Health, a state of Knowledge Review*. UNEP, CBD, WHO. https://doi.org/10.13140/RG.2.1.3679.6565 Newman, D. J., & Cragg, G. M. (2012). Natural Products As Sources of New Drugs over the 30 Years from 1981 to 2010. *Journal of Natural Productws*, *Review*(75),

		Sustainability, *1*(7), 369–374. https://doi.org/10.1038/s41893-018-0100-6 Royal Botanic Gardens KEW (2017) State of the world's plants. Chapter : Useful plants- Medicines, at least 28,187, p 22–29. https://stateoftheworldsplants.com/2017/useful-plants.html	311–335. https://doi.org/335 dx.doi.org/10.1021/np200906s World Health Organization (2013). WHO traditional medicine strategy: 2014-2023. Geneva: World Health Organization; 2013.

14.3.5. Trends in Co-Production

14.3.5.1. General (across all units of analysis)

14.3.5.1.1. Biodiversity loss: negative impacts of long distance trade and general habitat loss

SUMMARY The World Health Organization recognizes that 65 – 80 % of the global population depends almost entirely on NMPs (Natural Medicinal Products) directly available from nature for their health care (WHO 2013). Much knowledge is held by Indigenous Peoples who manage or have tenure rights over at least ~38 million km^2 in 87 countries i.e. a quarter of the world's land surface, and intersects about 40% of all terrestrial protected areas and ecologically intact landscapes (Garnett et al 2018). Medicinal Plants are well demonstrated to have positive health properties besides being integrated in a diversity of medical systems (Hamilton 2004, Hamilton and Aumeeruddy-Thomas 2013, Leaman 2015, R.B.G. KEW 2017). 70 000 medicinal plants species, i.e.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). The R.B.G. KEW Project on medicinal plants identified 28 187 medicinal plant species at the global level, a figure likely to increase as prospection progresses (R.B.G. KEW 2017). Phylogenetic studies reveal the high predictive power of traditional medicine in bioprospecting (Saslis-Lagoudakis et al. 2012, 2014). Trends in co-production: It is estimated that 21% of known medicinal plants i.e. 15 000 are threatened (Schippmann et al. 2006). Decrease of access to customary land by Indigenous peoples in biodiversity rich áreas (Garnett et al 2018, Ding et al 2016), loss of ILK (Aswani et al. 2018), over-harvesting for long distance trade, changes in land uses are multiple factors that contribute to threats over NMPs and their accessibility for health care at the global level. Long distance trade of animal medicinal products is recognized to exert major threats on many animal species (Alves and Rosa 2005). The exponential increase in the use by urban dwellers or by industries of natural medicines exerts threats that create a variance between source área users (decreasing) and urban dwellers increasing. The latter however use a smaller proportion of medicinal plants known (Hamilton 2004, Schippmann et al 2006.

The potential in identifying natural medicinal products from present terrestrial and marine biodiversity is "buffered" by the major advances in techniques over the last 30 years as well as major discoveries in new áreas of investigation such as marine products or fungi (Newman and Cragg 2012, Alves et al. 2018). Major advances allow synthesizing new molecules based on information related to known biodiversity incorporated in very large libraries. Synthetizing molecules that mimic nature thus may continue even if elements of nature have disappeared. Spatial variance: Joint production of conventional medicine is mostly based in developed countries as opposed to developing countries, and lack of access to converntional medicines in developing countries is well demonstrated, partly because of lack of conventional practiners, as well as high costs of medicines (Bodeker et al. 2005).

Narrative review based on literature (500-2000 words) There are major threats to natural medicinal products, especially from overharvesting for long distance trade in addition to general habitat loss that threaten biodiversity (Schippmann et al. 2002, Hamilton 2004, Hamilton and Aumeeruddy-Thomas 2013, Wolff et al. 2017). According to Schippmann et al. (2006), 15 000 medicinal plant species are threatened. Increasing volumes, harvested or poached largely from the wild, are traded to local, regional and international markets to meet demands that emanate mainly from consumers in emerging countries and the global north, including the pharmaceutical industry as well as a popular botanical medicine industry (Kuipers 1997; Lange 1998, 2002, Schippman et al 2002, Richerzhagen 2010,Wolff et al 2013, Kloos 2017, Pordié and Hardon 2015). These products are used as medicinal products but also in the growing nature-based personal care and nutraceutical markets and there seems to be a correlation between food products homogenization due to agricultural modernization and increasing needs of food supplements. The threat to medicinal natural resources fragilizes the health systems of local societies in developing countries who depend heavily on traditional medicine (Farnsworth et al. 1985; Farnsworth and Soejarto 1991, Cunningham 1993, Lama et al 2000, Ghimire et al. 2004, Richerzhagen, 2010, Hamilton 2004, Hamilton and Aumeeruddy-Thomas 2013, Leaman 2015, Wolff et al. 2017).
Collecting medicinal plants and poaching animals for trade has collateral effects on poverty and development (Cunningham 1993, Schippmann et al. 2002, 2006, Leaman 2015, Wolff et al. 2017). Collecting and poaching generate some income that feeds into local economies. But uneven levels of knowledge, power and access to international markets often mean that people involved in wild harvesting are not necessarily from the localities where they collect, thus trespassing customary lands with little or no regulations at national levels (Ghimire et al. 2004). Industrial demand for cheap raw natural materials to extract medicines can also feed into market dynamics that are unfavorable to local groups. Cheap price of herbal medicines in developing countries as well as their connection with local medical practices and cultural concepts also favors their utilization rather than the use of modern drugs even among IPLCs that have migrated to towns (Cunningham 1993). Other factors such as deforestation, logging, extension of pastures and changes in land use including development of industrial plantations as well as climate change, also represent major threats upon access to resources and consequently on local and global populations health.

14.3.5.1.2. ILK loss: increased recognition and save-guarding processes

Summary: IPLCs still living in extended biodiversity- rich áreas of the planet are more able than urban dwellers to identify NMPs and genetc resource and arewell-known to nurture their co-extence with people as a result of cnceptualizations of nature and culturally-based health systems. Territories with different forms of tenure rights and a diversity of management systems vover at least 28 per cent of global land area, including at least 40 per cent of the area that is formally protected, and some 37 per cent of all remaining terrestrial areas with very low human intervention (Garnette et al 2018). Their strong level of participation in international for a may lead to better recognition of their rights and knowledge systems.

Narrative review :

Initiatives by the International Society of Ethnobiology in 2012 (Belem Declaration), the CBD since 2012 (articles 8j and 10), the UN Declaration on the Rights of Indigenous Peoples, the UN Sustainable Development Goals, and a diversity of programs (The Forest Peoples Program, the WWF, UNESCO, KEW RBG People and Plants Initiative 1992-2000) and IPBES, show a significantly stronger level of participation of IPLCs and representation of ILK in global environmental management that should potentially benefit the save-guarding of their rights and knowledge. Many grass-roots initiatives are also developing such as Himalayan Amchi Association and Nomad projects in the Himalayas indicating a general uptake of these changes at global level (Blaikie et al 2015).
However, since the initial focus of the World Health Organization (WHO 1978) Alma Ata Declaration on providing “health for all” through primary health care delivered by rural clinics and barefoot

doctors, WHO's Beijing Declaration (WHO 2008) explicitly connects the unmet objectives of Alma Ata and the United Nations' Millennium Development Goals with traditional medicine (WHO 2008). By officially acknowledging—and even encouraging— traditional medicine's role in the provision of primary health care rather than perpetuating its dismissal as an obstacle to health development, the Beijing Declaration articulates a major shift in the official perception and status of traditional medicine (Kloos 2017). This major shift may also have negative results on the richness of local medicines due to normalization processes of these medicines that it entails (Kloos 2017). It has also inevitably led to a larger utilization and recognition of global interest to the later and, therefore increased dependency on natural Medicinal products and save-guard of ILK. There is also an increased effort to map and establish conservation areas linked to local communities (ICCAs https://www.iucn.org/content/indigenous-and-community-conserved-areas-bold-new-frontier-conservation), in order to face many conflicts with local customary lands. Such conflicts may emerge with more conventional conservation areas approaches (see Nature chapter) and an increased recognition of the importance of biocultural landscapes (e.g. UNESCO Intangible Heritage landscapes, or Global International Agricultural Heritage Sites, GIAHs of FA0), as well as small scale farming systems and agroecology that are promoted worldwide by FAO and different national and regional policies. These areas potentially host a significant proportion of NMPs and, are connected to ILK in practice. Concretely loss of medicinal plant species are still due for instance in European grasslands to abandonment of traditional extensive pasture management with for example loss of wild Arnica montana populations (Ellenberger 1999) although conservation protection rules have been established such as the European Union Habitat Directive. This example shows that unless the people that were associated to the practices that maintained these anthropogenic landscapes and habitats are supported to stay and that their practices are recognized and that the products are highly valued, such habitats will irremediably slowly disappear.
Acknowledgement of non-modern medical systems is mainly registered formally for scholarly systems, but little data is available for ethnomedical or folk systems except that some are not legally acknowledged (e.g. France Folk medicine is illegal when it relates to selling the products, Thévenin 2013) and/or no facilities exist within the countries to support their use. Much of the recognitions are simply informal.

14.3.5.1.3. New drugs development: the continuing dependency on NMPs

Summary: The analysis of the origin of all chemically produced medicines for all illnesses over a period of 30 years shows that they rely to a large extent on NMPs: more than 25% of new chemical entities of drugs for all diseases treated at the global level are derived from natural products and more than 70% of drugs to treat cancers derive directly from NMPs (Newman et al 2003, Newman and Cragg, 2012). There has been a steady increase in drugs found based on natural products over a period of 30 years for all major diseases at the global level (Newman et al 2003, Newman and Cragg 2012). Over the last 50 years was reported the isolation of more than 30,000 new compounds of marine origin and the approval of more than 300 patents, indicating that new discoveries are moving very fast (Alves et al. 2018) and similar patterns are known for fungi, based on existing asiatic pharmacopeia which has yet been little studied.

Narrative review : In the field of new drugs discoveries, Newman and Cragg (2012), show that the opportunity to find new drugs over the last 30 years for all diseases worldwide is still very highly dependent upon natural products, or synthesized products that mimic natural products as opposed to purely synthetic products based on recombined molecular chemical approaches. Regarding cancer, Newman and Cragg (2012) show the following: "among the whole category of anticancer drugs approved worldwide, the 206 approved agents can be categorized as follows: Biological (26;13%), Natural (27; 13%), NB, Natural Botanical (1; 0.5%), ND, or semisynthetic derived from a natural product (57; 28%), Synthetic (44; 21%), S/NM, synthetic, natural mimic (18; 9%), S* (20; 10%), S*/NM, synthetic natural mimic (8; 4%), and Vaccine (5; 2%). If one then removes the high molecular weight materials (biologicals and vaccines), reducing the overall number to 175 (100%), the number of naturally inspired agents (i.e., N, ND, S/NM, S*, S*/NM) is 131 (74.9%)" Given these trends, finding new drugs in the future is likely to still continue to depend heavily on natural products, including microbe hosts and complex biotic interactions because nature has already selected active compounds over evolutionary times whereas finding a new drug departing from zero is less susceptible to recreate an active agent".

14.3.5.2. By Units of Analysis

Trends/Change WITHIN a predefined unit of analysis; LULC can change within that unit. Summarize general changes within unit and general impact of that change

Summary: Biodiversity potential is decreasing at a rate that is higher than 20% as demonstrated by the Regional IPBES Reports. Loss of NMPs is due to loss of biodiversity at global level and loss of knowledge, especially traditional orally transmitted pharmacopeia and changes in land uses (Aswani et al 2018). Biodiversity rich areas that are most threatened and which deliver many NMPS are either those where human, directly-driven threats exist (Humid tropics), those particularly vulnerable to climate change (Mediterranean region, High mountain ranges, Andes, Himalayas and others) where constraining biotic conditions have favored many natural active compounds, those where pollution may heavily affect the substrates (Ocean, littoral habitats), industrial cultivation areas. Variance also relate to rural/ natural v/s urbanised..

Unit of Analysis	Direction of arrow	Rationale/ justification for why you think this trend is happening
1. Tropical and subtropical dry and humid forests	**NMPsDecrease (_2)** But new drugs development based on NMPs potentially stable or potentially increasing (see narrative above) NMPs in Agroecosystems and in domestication processes potentially increasing (1)	Deforestation causes (see Nature and drivers sub-chapter). Climate change affecting subtropical dry forests: Anthropogenic parklands managed locally may buffer loss of NMPs Shifting cultivation areas replaced by industrial plantations and ILPS evicted: major loss in humid tropical forests Agroecosystems (complex rural agroecosystems, periurban new developments) possibly increasing + Domestication of NMPs under high international demand underway (see Simons and Leakey 2004). More ethno botanical work lead to discoveries by researchers in remotest areas and new potentials for new drug discovery (e.g. Prescott et al. 2017)
2. Temperate and boreal forests and woodlands	Temperate forest NMPs, decrease(-1) Boreal forest **NMPs** decrease	General increase of temperate and boreal forests due to agriculture abandonment, but likely loss of many NMPs that were linked to anthropogenic landscapes associated to landscape mosaics (forests and fields). Climate change affecting ILPCs living in boreal regions, loss of access to pasture lands. Fragmentation of landscapes due to modernization, road construction etc… Loss of direct knowledge by IPLCs, due to changes in lifestyles
3. Mediterranean forests, woodland, and scrub	**NMPs Decrease (-1)** in southern Mediterranean countries **NMPs (+1)** in Northern Mediterranean region	Fire affecting forests in Mediterranean. Land abandonment and natural afforestation successions leads (ex: by pine trees) to current decrease in species richness due to pine allelopathic effects, but acknowledgement that longer successions will reduce these effects. Many traditional tree savannah-like agroecosystems, now protected (very large areas of Dehesa in Spain and Montades in Portugal) among the highest open vegetation biodiversity richness in the Mediterranean, potentially hosting high levels of NMPs.

		In Maghreb countries, high loss of scrublands areas due to over-grazing and improved domestic animal land races. Land abandonment leading to reforestation and loss of open vegetation NMPs
4. Tundra and high mountain habitats	Tundra: no clear trend available High mountains (and plateaus): predicted less loss with Medicinal plants than anticipated non medicinals in one case study: **NMPs (_2) Decrease**	Tundra suffering from Climate change. Case study of ILPC group moving into Tundra area and learning from local groups using very large amounts of NMPs (Jernigan et al 2017) Mountain Habitats: overharvesting and poaching + habitat loss due to climate change. Experimental prediction of medicinal plant loss in relation to global warming on the Tibetan plateau shows that medicinal plants' potential loss is lower (27%) as opposed to non-medicinal (40 % predicted loss) due to the deep rooted systems of most medicinal plants (Klein et al 2015) Undergoing research using genetic transfer of medicinal plants potential, likely to yield more medicines in the future based on NMPS while decreasing impacts on harvesting, although such medicines have yet to be tested (Hao et al 2015) Some loss of knowledge by a few case studies but much work engaged in exploring ILK and impact of many known TNMPs as well as developing drugs from the latter by researchers
5. Tropical and subtropical savannahs and grasslands	NMPs : no clear evaluation available	Over-grazing Lack of local management due to outmigration Climate change and droughts But lack of precise data for thus Unit. But signs of research and development developed locally by some African countries including coordination with other African countries) to develop products for diseases occurring locally from MPs from Soudano-sahelian region (Titikpina et al 2016)
6. Temperate grasslands	NMPs (-2) Decrease	Decrease in extensive pastoral management, that were very favorable to NMPs (e.g. Ellenberger 1999) Afforestation and loss of species richness in new stages of forest succession.
7. Drylands and deserts	NMPs (-2) Decrease	Overgrazing linked to changes in number and types of animal landraces and their diets (fed with "granule") in order to increase production and subsequent impact on many species that contain fibres. Climate changes effects; detrimental to biodiversity
8. Wetlands – peatlands, mires, bogs	NMPs (-2) Decrease	In northern Africa, 20 % of the wetland plant species identified as economically important are threatened with extinction. The main threat is habitat loss and degradation (affecting 95 % of species), although non sustainable level of harvest is identified as a major threat to some species (Juffe-Bignoli et al. *2012*). Other usual drivers lead to loss of habitat (see Nature sub-chapter)
9. Urban/semi-urban	NMPs decrease (-2) Semi-Urban : (+1) increase	Urban expansion leading to loss of habitats, but urban demands leading to revitalization of urban hinterlands to feed the demands of urban needs, especially relevant for food. Loss of biodiversity within urban areas show many different facets
10. Cultivated areas (including cropping, intensive livestock, farming, etc.)	Industrial cultivated areas: NMPs (_2) decrease Agroecosystems and agroecological farming systems: **NMPs (°+1) : increase**	Cultivated areas, most important driver of natural habitat loss + pesticides highly affect NMPs Agroforestry and agroecological farming systems are increasingly supported by a wide range of policies

13. Inland surface waters and water bodies/ freshwater	Down	General issues of pollution likely to interfere with NMPs
14. Shelf ecosystems (neritic and intertidal zone, estuaries, mangroves) LUC ?		Acidification processes and pollution likely not to favor NMPs
17. Coastal areas intensively managed and multiply used by people	NMPs down	Pollution of diverse types

14.4. Impacts on good quality of life

Summary: Status of Impacts on Good Quality of Life:

Natural Medicinal Products representing genetic resources from the perspective of the Nagoya Protocole, have a high and substantial impact on global well-being. They are primarily used at the global level by traditional subsistence and small-scale harvesters, whose livelihoods are highly dependent upon nature (Leaman 2015, Garnett et al 2018), but also by an increasingly large number of urban dwellers with high demands for natural products for diverse uses (health, cosmetics, home care, neutraceuticals etc.) (Hamilton 2004, Schippmann et al 2006, Wolff et al. 2017). 65- 80 % of the world's population rely almost exclusively on NMPs (WHO 2013) due to lack of access to conventional medicine. The large diversity of medical pharmacopeias existing to date has a very high cultural and relational value (Hamilton and Aumeeruddy-Thomas 2014; Leaman 2015). Impacts on biodiversity and ecosystems are also high as it has been argued that high local value of NMPs is a major incentive for protecting biodiversity (Hamilton 2004). It is also well demonstrated that harvesting for long distance trade often leads to over-harvesting due to the very bad redistribution of benefits along the chain trade. Furthermore the market underestimates the value of biodiversity, and policies and institutions for correcting the distortion are lacking (TEEB 2009a, b). The market for NMPs and genetic resources are concentrated between very large firms that have merged In agrochemical, agro-seed, and pharmaceutical ths representing large global life-science companies and strengthened their position in the market (Richerzhagen 2011). Although the industry argues that genetic resources have become less important, data indicate that in Germany, for example, users expect to constantly use genetic resources or even expand their use (Richerzhagen 2011). Direct impacts on global wellbeing are known for many important diseases (WHO 2013). For example, regarding diabetes, it is estimated that 422 million adults are affected; it is a Global health and economic burden. 656 flowering plant species are used traditionally for diabetes. Some of these species have provided cues for new drug discoveries that are widely used (R.B.G. KEW, 2017). In 2000, US$17 billion were spent in the US on traditional herbal medicines. In 2003, the World Health Organisation 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$83 billion (R.B.G. KEW 2017). In 2006 the pharmaceutical market comprised US$ 640 billion, and 25–50% of the products concerned were derived from genetic resources from NMPs . The agricultural seed market's value was US$ 30 billion in 2006, and all of its products are derived from genetic resources from nature (TEEB 2009a). **Trends :** Due to major changes in land use, threats to biodiversity, extractive and mining activities, loss of ILK and changes in life styles, and other indirect drivers, such as climate change, urbanization, land grabbing and abandonnement, it is estimated that the access to NMPs is generally decreasing with important impacts on well-being for the large proportion of the world population relying heavily on these for their health. At the opposite end, increased use of NMPs by urban dwellers has positive impacts on GQLs in towns although a clear analysis of effective impacts is not available at the global level. It is demonstrated (high evidence) that more than 20 % of modern drugs currently used for all diseases at the global level are based on leads from natural molecules, sometimes identified by science such as for antibiotics, or based on ILK, such as aspirin, vincristine or taxol. More than 70 % drugs used to treat cancer are based on NMPs (Newman et al. 2003, Newman & Cragg 2012). **Trends in values of drugs based on NMPs** In 1997, 71 drugs from NMPs earned more than US$500 million each and 27 blockbuster drugs from NMPs earned more than US$1 billion each per year. Today more than 50 % of the drugs in the market are natural products or derived from natural products. In 2004 the pharmaceutical market topped US$500 billion (Richerzhagen 2010, 2011). It has been estimated that the pharmaceutical industry earns about US$32 billion a year in profits from products derived from traditional remedies (Richerzhazen 2010, 2011). This is a 7 percent increase over 2003 and a 28 percent increase compared to 2001. The industry is concentrated in the US and Europe. The already large and profitable pharmaceutical industry has been rapidly consolidating over the past few years. The list of top Top 35 Worldwide Ethical Drug Sales for 2000, 2001, and 2002 of Natural Product-Derived Drugs is available *(Butler 2004).***Spatial variance** is high, with very high reliance on NMPs in rural areas by subsistence farmers, fishers and harvesters, yet having little access to conventional drugs (WHO 2013). Spatial variance regarding benefits from drug discoveries is also high because a majority of pharmaceutical industries are based in US and Europe. Spatial variance regarding diseases for which pharmaceutical industries invest, is mostly diseases that affect developed countries although there is a general trend towards Universities from developing and developed being more involved in research during the last decades (Richerzhazen 2010).

14.4.1. Different types of value

14.4.1.1. What is the NCP contribution

14.4.1.1.1. Intrinsic values:

This NCP has major intrinsic values because fundamentally all natural secondary components produced by plants, animals or fungi, have evolved over millions of years with the major role of protecting plants, animals and fungi from predators, diseases and or to attract pollinators and /or mating partners (Efferth and Greten 2013, Petroni et al 2017). It is precisely these intrinsic values that are observed and probed by ILK and pharmaceutical research. These intrinsic values are inherent to nature's evolution processes over millions of years.

14.4.1.1.2. Relational and holistic values

For ILPCS, NMPs have significant relational and holistic values relating to their overall relationship to nature, land and modes of interactions with natural elements that do not consider only active principles but also the inner-self of non-humans (Descola 2005, Ingold 2000). NMPs have concomitantly symbolic as well as material values, both resonating with body and mental health and diseases conceptualizations, often seen as an imbalance with the environment as a whole (Zimmerman 2011). Restoring the balance through health practices also means strong relational values linked to the power of healers and also the relationship between the patient and other sections of the society (e.g.Lama et al 2001). Overall health impacts of TNMPs can be measured by the percentage of people known at the global level that relies almost exclusively on the latter, a proportion that varies between 60 % to 80% (WHO 2013), who can also be visualized in terms of areas inhabited by the latter (see Figure 7)

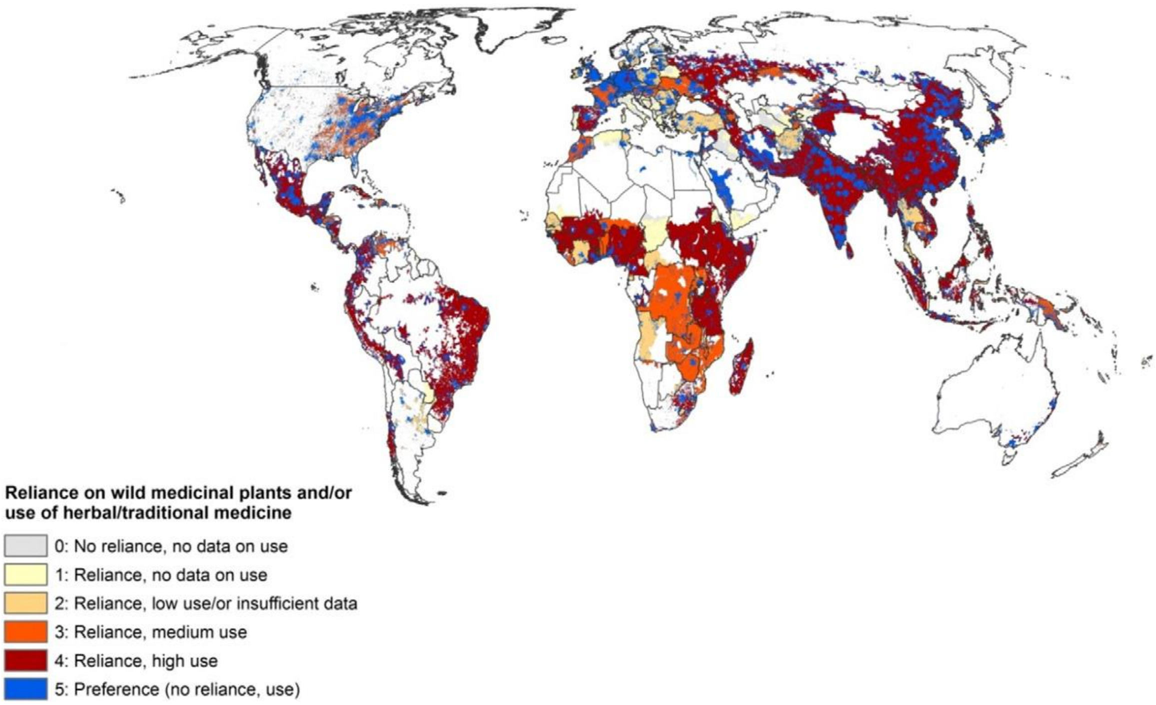


Figure 7: Areas where there is a combination between reliance on wild medicinal plants and use of herbal/traditional medicine (white areas indicate areas with a population b2 people/km2) (source: Wolff et al. 2017)

4.1.1.3. Economic values are huge because firstly NMPs represent an opportunity through being directly accessible in nature for people who live within natural environments, such as IPLCs. This could be converted into what they would pay if they had to replace this with modern drugs. Buying these drugs on local markets are also less expensive than modern drugs (Cunningham 1993), one of the reasons of the extensive long trade market of NMPs within Africa for instance that also leads to their overharvesting. While NMPs are preferred for socio-cultural reasons, their use can also be analyzed in relation to remoteness and non- availability of conventional practitioners as shown by Wolff et al 2013. Reliance on medicinal plants for health has presented by Wolff et al 2017 (see Map above) shows the following: "Relatively high reliance is also found in mountainous communities of Indonesia, Pakistan, West China, Bhutan and Nepal where physical accessibility to primary healthcare is low. In Nepal's rural areas, high poverty and unaffordability of modern medication has made most of the population reliant on traditional herbal medicine for healthcare (Shrestha and Dhillion, 2003). In South America, high demands can be found in Brazil, around the Amazonas region, as well as in mountainous regions of Peru, Colombia and Guyana, where a medium availability of physicians combined with remoteness of populations are the most determinant factors. Island states of the Indian and Pacific Ocean, such as Samoa, Papua New Guinea. or Timor-Leste also show high reliance's due to their insufficient availability of physicians and their geographical isolation. However "For demands depending on local supply, such as many cultural and locally important provisioning ES, growing demand will most likely foster pressures on local ecosystems, and can lead to declines in ES supply if management does not adapt to these changes, or in case management options are not available. For example, in several areas in Africa and Asia, specific wild medicinal plant species are being frequently overharvested, in particular in areas and times of disease outbreaks re lated to HIV or Malaria (Anyonge et al., 2006; Ngarivhume et al., 2015)"
Loss of species due to overharvesting could also be converted into the amounts of money they have represented for humanity as leads for developing new drugs.

The economic value of new drugs is known. It should be noted, however, that numbers of approved drugs/disease do not correlate with the "value" as measured by sales. For example, the best selling drug of all is atorvastatin (Lipitor), a hypocholesterolemic descended directly from a microbial natural product, which sold over$11 billion in 2004, and, if one includes sales by Pfizer and Astellas Pharma over the 2004 to 2010 time frames, sales have hovered at $12−14 billion depending upon the year. The economic value of botanicals is another sector which is worth billions as detailed above (2.2.1)

14.4.2. How do we measure that value/contribution?

Methods of measuring this NCP impact

4.1.2.1 Intrinsic values: cannot be measured, being intrinsic!

4.1.2.2. Relational and holistic values. Area at the global level where people are heavily reliant upon NMPs, mostly inhabited by poor, local communities as shown on MAP proposed by Wolf et al 2017 (Figure 7). This geographical representation of the importance of areas and countries concerned gives a picture of the importance of reliance and major variations upon Natural Medicinal Products at the global level. Direct interactions with IPLCs and other actors are the most direct ways to capture relational and holistic values (Sterling et al. 2017, Caillon et al. 2017). Context specific indicators are difficult to identify ex-situ. Consensus approaches, analysis of social exchange networks, free listing approaches can be used locally as methods to evaluate relational and holistic values.

14.4.3. Substitutability

Human activities that replace this NCP: this is mainly the design of drugs and synthesizing natural molecules by industry (see above) with some drawbacks that are still quite unknown. It is generally hypothesized that using one active molecule cannot replace a whole plant which has a "totum" effect meaning synergies and balance between all the active principles contained within the plant.

Homeopathic medicine is probably the most innovative substitute that has been invented in modern times in Europe by Hannemann in 1756 and which is gaining recognition. This approach is among the most revolutionary substitute of natural based products because it uses only the memory of these products, something similar to the products energy. Although this medical practices is highly debated (Ernst 2002 http://onlinelibrary.wiley.com/doi/10.1046/j.1365-2125.2002.01699.x/epdf), it is efficiently replacing chemical medicines for a significant proportion of the world population, being very popular in Europe, US, India etc. It contributes to a large extent to save the natural medicinal products when used in infinitesimal dilutions (instead of alcohol extracts).Genetic engineering and transfer from medicinal species to crops (new GMOs) are being evaluated by new biotechnological techniques (Hao and Xiao 2015).

14.4.4. Status and Trends in impact (value)

Hamilton (2004), analyzing trends of use at the global level shows that the global demand for herbal medicine is not only large, but growing. The market for Ayurvedic medicines is estimated to be expanding at 20% annually in India (Subrat et al. 2002), while the quantity of medicinal plants obtained from just one province of China (Yunnan) has grown by 10 times in the last 10 years (Pei 2002). Factors contributing to the growth in demand for traditional medicine include the increasing human population and the frequently inadequate provision of Western (allopathic) medicine in developing countries. Natural medicinal products therefore play a major role for health care at the global level, but also represent a huge economic resource.

14.4.4.1. Trade of medicinal plants and new drugs development

New pharmaceutical drugs are traded which facilitates the economic evaluation at the global level. These values may be used as proxies of the value of drugs based on NMPs or synthetized through mimicking nature structures. Example: In 1997, 71 drugs from NMPs earned more than US$500 million each and 27 blockbuster drugs from NMPs earned more than US$1 billion each per year. Today more than 50 % of the drugs in the market are natural products or derived from natural products. In 2004 the pharmaceutical market topped US$500 billion (Richerzhagen 2010). It has been estimated that the pharmaceutical industry earns about US$32 billion a year in profits from products derived from traditional remedies (Richerzhazen 2010). This is a 7 percent increase over 2003 and a 28 percent increase compared to 2001. The industry is concentrated in the US and Europe, followed by Japan where national insurance policies favor Pharmaceutical industries (Com.C. Zayas). The already large and profitable pharmaceutical industry has been rapidly consolidating over the past few years. The list of top Top 35 Worldwide Ethical Drug Sales for 2000, 2001, and 2002 are Natural Product-Derived Drugs is available (Butler 2004). In China alone, the market value of Chinese *Materia Medica* was estimated to be US$83.1 billion in 2013 (World Health Organization *2013*).

Olsen's evaluation of trade of Medicinal Plants from Nepal shows the following: the annual total trade is estimated at 2400-9400 tones with a trade level in 1997/98 of 6254 tones. India is by far the dominant export destination; and there is very low domestic demand for raw plant materials in Nepal. The total cif export value is estimated at USD 3.2-12.8 million with a value of USD 8.1 million in 1997/98. The top five species are *Nardostachys grandiflora, Swertia chirayita, Neopicrorhiza scrophulariiflora, Zanthoxylum armatum* and *Sapindus mukorossi*; together they make up more than 52% of the total value. It is argued that the findings are conservative and that there may be scope for increasing the value of medicinal and aromatic plants to the Nepalese economy. There is strong evidence that the trend of use of natural products for medicines and other new uses of the same species for cosmetics, healthy nutriments and production of herbal teas is rising in urban areas (ten Kate and Laird 1999, Hamilton 2004).

14.4.4.2. Impact on relational and holistic values

Worldwide threats upon biomes, ecosystems and habitats due to a diversity of drivers are likely to decrease access to natural medicinal products as well as to the knowledge held by Indigenous Peoples and Local Communities (IPLCs), who primarily co-produce this NCP (Hamilton and Aumeeruddy-Thomas 2014). This knowledge is also crucial for the development of modern drugs some of which are still being tested (Miller 2011). However, this knowledge is a highly adaptative and it is likely that IPLCs may still identify new species in new environments as shown by displaced communities (Jernigan et al 2017. Changes in habitat such as increasing amounts of secondary forests in the tropics is also likely to yield new drugs as it has been shown that secondary forest species yield high amounts of N MPs Gavin (2009). Psychologic and mental health issues are however very likely to affect IPLCs that are evicted from their territories due to high sense of place and belonging to their land, including linkage to ancestors. Many IPLCs leaving rural areas for town are still very heavily depending on NMPs from market areas (Cunningham 1993).

The increase in modern agricultural areas with high levels of chemical inputs does not favor production of natural medicinal products.Traditional agroecosystems and pastoral lands under customary and common property regimes managed by indigenous peoples and local communities at the global level are also threatened by a diversity of complex drivers but still represent important sources of natural medicinal products (e.g. high Himalayan Pastures, Ghimire et al 2006). A dominant situation of lack of national recognition of rights of IPLCs over customary lands has direct consequences on their ability to enforce control over-harvesting practices by external commercial collectors. Overall development of revitalization of ILK and national, regional and global recognitions is likely to reinforce the relational and holistic values linking IPLCs to NMPs. Increased demands for botanical medicines from markets is also helping in self-esteem regarding ethnomedicines besides bringing economic revenues.

14.4.5. Indicators of NCP impact

14.4.5.1. Indicators by value

Value type	Indicator / Proxy	Rationale/ justification for why we this indicator/ proxy was selected	Data set	Scale of Measure – space	Scale of measure - time
Intrinsic		Good evidence	Many papers and books in evolutionary ecology on secondary compounds. Roles for other species: Petroni et al 2017. The intrinsic value of NMPs is highly affected by decrease of population size of NMPs that are traded and fragmentation of habitats that may in some cases lead to extinction. 15 000 species of NMPs are known to be threatened	Global	
Economic	Figures and percentages of wild plant collection harvested, traded. New drugs production and sales figures	Trade figures available for major export countries and import countries And values of economic benefits by Pharmaceutical Industries	Schippmann U, Leaman D., Cunningham, A. B. (2006). CHAPTER 6 A COMPARISON OF CULTIVATION AND WILD COLLECTION OF MEDICINAL AND AROMATIC PLANTS UNDER SUSTAINABILITY ASPECTS. In D. L. R.J. Bogers, L.E. Craker, D. Lange (Ed.), *Medicinal and Aromatic Plants* (pp. 75–95). Richerzhagen, C. (2011) Effective governance of access and benefit-sharing under the Convention on Biological Diversity. Biodiversity and Conservation 20, 2243-2261, doi:10.1007/s10531-011-0086-0 (2011).	Global	1decade, 2000-2010
Value Relational	Maps showing areas where humans mostly rely NMPs for health	IPLCs rely on medicinals, firstly because of their proximity with nature, nature conceptualizations, and subsequently use of NMPs as an intrinsic element for healing, + roles of specialists (Healers) that	Wolff, S., Schulp, C. J. E., Kastner, T., & Verburg, P. H. (2017). Quantifying Spatial Variation in Ecosystem Services Demand: A Global Mapping Approach. Ecological Economics, 136, 14–29. https://doi.org/10.1016/j.ecolecon.2017.02.005 World Health Organization (2013). WHO traditional medicine strategy: 2014-2023. Geneva: World Health Organization; 2013.		

		are able to interact with nature, and consideration that NMPs are not only active principles Also considering, their limited access to conventional practitioners and medicines.			

14.4.6. Trends by user group

Find examples from literature, how would they be affected

User Type	User Group	Direction of arrow	Rationale/ justification for why you think this trend is happening
Livelihood categories	Universal		
	Subsistence food gatherers (non-marine)	Decrease	Strictly substistence food gatherers means that they are still living in close contact with nature and therefore are still relying heavily on NMPs. If they leave for urban areas, some studies in south East Asia show that they maintain linkages with previous habitats where they leaved for bushmeat and or other products or even may serve as a link to selling non timber forest products. Their overall existence and customary territories are however threatened by habitat change.
	Subsistence food gatherers (marine)	No substantial data found	No data
	Subsistence Farmers	Decrease	Subsistence farmers rely entirely on their farm lands and in a world where goods including conventional medicines are too expensive, they certainly still rely on their own access to NMPs within their lands. They may even harvest the latter for trade given the increase in trends of trade of NMPS for global markets. This has been shown for many cases (See Olsen for Case study in Nepal). But subsistance farming is decreasing globally.
	Pastoralists (including subsistence ranchers)	Decrease	Same as for subsistence farmers.
	Commercial fishers	?	?
	Commercial Farmers	Decrease	Being commercial farmers, they most probably have a little more access to goods and services including conventional medicines and health services.
	Commercial ranchers	Decrease	Same as above
	Commercial foresters	Decrease	Same as above
	Energy and mining	No Data	No data/ Mining areas are not convenient for NMPs
	Industrial	Decrease	Most probably relying entirely on conventional Medicines and Health Care
	Recreation and Tourism	Up	People in search of natural environments for leisure, are rich and are the most likely to be using more NMPs for their own health- care and or personal care as shown by many papers showing a flourishing demand for nature-based products.
Residence categories	Urban coastal	_	
	Urban inland	Increase	Urban areas throughout the planet have an increasing demand for NMPs
	Rural coastal		
	Rural inland forest	Up	Tropical, sub-tropical and dryland savannah face many diseases and rely heavily on NMPs. Demand is likely to be increasing with demography and remoteness
	Rural inland savannah, grassland	Up	Same as above
	Rural inland desert, tundra, barren	Up	Same as above
	Nomads	Up	Same as above

Summary paragraph on Status of Impacts on Good Quality of Life:
NMPs throughout the world are primarily used by traditional subsistence and small scale harvesters (farmers, herders, hunter gatherers, fishers) whole livelihoods are highly dependant upon nature (Leaman 2015, Richerzhagen 2010). Although this group is highly diverse, they represent what is currently termed as IPLCs in the GA (Chapter 1 GA). WHO (2013) refers to some 80 % of the world populaion in 2013 that relied almost exclusively on NMPs because the latter are connected to traditional medical systems to which this very diverse groups are linked culturally and also because of connectedness to land and ancestral practices (Cuerrier et al. 2015).
(B) Diverse reviews (Butler 2004, Newman et al. 2003, Newman & Cragg (2012) demonstrate that most modern drugs have used leads from natural molecules, sometimes identified by science such as antibiotics or based on ILK, such as aspirine, vincristine and taxol (major anticancer drugs), that have had hugh impacts at the global level. The importance of the benefits of the trade of these drugs is an indicator of the importance of their use at the global level (Hamilton and Aumeeruddy-Thomas, 2013).

Summary paragraph on Trends in Impacts on Good Quality of Life:
(Although the impact on good quality of life is still huge at the global level for IPLCs including myriad of groups operating in local territories, it is well established, that urbanization rate is exponential at the global level showing that people are leaving their local set-ups for a diversity of reasons, including land grabbing mining and other extractive activities including industrial plantations, or armed conflicts, climate change etc.

14.5. Summary

14.5.1. Status

Intrinsic values
Trends in negative changes in this NCP are linked to global biodiversity loss linked to a diversity of drivers, including land-use changes, climate change (see NCP Climate), urbanization and industrialization of agriculture as well as increased dependency urban populations at global level on botanical medicines, animal medicines and nutraceuticals to compensate industrial food homogenization process. The intrinsic value of NMPs may be highly affected due to issues of species population survival. The intrinsic value of genetic resources, crops, ther wild relatives are also highly threatened because of overall losss of biodiversity and extension of low-biodiversity industrial agricultural systems.
Economic values
Global trends in NMP trade lead to some extent to enrichment of traders, new nature-based botanical and nutraceuticals industries, to whole chains of people along the market circuit, but profits are rarely geared towards local harvesters. Conflicts between the latter and IPLCs in customary lands may arise. The latter may also lose access to essential resources for health without having access to other conventional sources of medicines. The major beneficiaries to date are the pharmaceutical industries who benefit from NMPs. Within that context Access and Benefit Sharing (ABS) arrangement rarely benefit to IPLCs because of many difficulties in claiming primary ownership of knowledge over resources. Ilk is indeed a shared knowledge which is often not privately owned while industries products are patented.

Relational values

Very high relational values link IPLCs to NMPs as wellas crop and animal landraces genetic resources but they suffer from major issues of eviction from their customary lands due to a diversity of drivers which have a very negative impact on IPLCs' health among other aspects of well-being. Knowledge loss linked to decreasing transgenerational transmissions, loss of local languages, in relation to a diversity of drivers (changes in lifestyle and education) is on-going while at the same time revitalization projects are flourishing as well as global andregional levels of recognition of ILK are increasing.

Loss of ILK may also have a negative consequence on discovery of new drugs, although more and more research are developing towards identifying and exploring the latter. Some very positive impacts are potential impacts of research and development developed regionally such as in Africa that aim specifically at providing pharmaceutically tested drugs adapted to local specific needs.

People living far from nature are developing a very huge demand for NMPs that seems to correspond to some fundamental needs to keep some "relations" with an ever vanishing nature in their lifestyles. This group of users however needs to be made aware of the problems of harvesting created in source areas.

Finally NMPs are very important for the development of new drugs for many emerging diseases especially in biodiversity rich areas such as the humid Tropics and Sub (tropical regions. Both traditional NMPs and new drugs tested and delivered by pharmaceutical industries, are essential to face these diseases and potential epidemic outbursts due to global exchanges and climate change. Similarly crop and wild relative resources are most important to face major global changes such as climate change and food security at the global level. Their loss endangers global well-being of humanity.

14.5.2. Similarities and differences across Units of Analysis and across User Groups

Overall trends show that most user groups that live in close proximity with nature and are subsistence –based are still highly dependent upon NMPs from nature and crop and animal genetic resources for food security in co-produced anthropogenic landscapesdespite biodiversity and habitat losses. To be noted, that degraded habitats and traditional agroecosystems may still yield substantial amounts of NMPS and crops and wild relatives genetic resources.

This NCP is particularly important for all people living in rural remote areas who rely heavily on NMPs from their direct environment for their health, presumably IPLCS and on diverse genetic resources for food and many other uses..

This NCP is also indirectly essential for the whole of the world's population because much of findings in new drugs are dependent to a large extent on NMPs as leads and or NMPs' structure to create Nature Mimics types of drugs that show to be highly efficient on a very large proportion of diseases. All new crops and new animal breeds depend on genetic resources available throught the planet.

14.6. References

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14.7. Search methodology

My key words: Natural Medicines AND or Traditional AND or Indigenous AND or Drugs AND or Medicinal Plants AND or Phytotherapy AND or Zootherapy AND or Human Health and or Access and Benefit Sharing AND or Bioprospecting AND or Biopiracy AND or Medicinal compounds AND or Aromatc plants. I used Web of Science, Core Collections, Access through CNRS

Being a member of the IUCN Medicinal Plants Specialist Group of the Species Survival Commission, I also used my own bookshelf and access to many PDFs that I already had on this subject.

Many books references are major references on this subject such as Schultes et al 2001: Plants of the Gods and I felt it added to the robustness of the evaluation to cite these.

Appendix 1:

BOX 1. Among a large diversity of pathways through which ILK identifies medicinal products, we may take the example of major poisons such as Strychnos or Aconitum species. The passage from their use as poisons to their use as medicinals is a well-known process in all medical systems, which stipulates that what can kill you can also treat you, an idea applied also in the very recent European Homeopathic medicinal approach formulated 200 years ago by Hahnemann (Relton et al. 2017). There are evidences that ILK is able to identify similar properties for similar plants beyond cultural boundaries across continents. For example the use of Strychnos species as arrow and dart poisons is well known in South America, Africa and South East Asia. As noted by Bisset (1995), in some cases, Malasian aborigenes defined many more types than did the taxonomist who identified the specimens. (Bisset 1995). Schultes (cited by Bisset 1995) identified more than 75 species used only by one group, the Kofan Indians of Columbia.

BOX 2

Ficus species, in particular, Ficus insipida and Ficus schultesi locally known as Ojé among the Shipibo-Konibo indians belong to a long list of "Plantas con madre", plants with a mother (a soul or a spirit) that teach and guide initiates through ingestion by the latter of such plants during shamanic initiations in the East-Central Peruvian Amazon (Jauregui et al 2011). While most shaman use brews of psychotropic plants such as Ayahuasca or Tobacco, among the Shipibo-Konibo, the initiates need to work with "the palos del monte" (rainforest trees)" that help the latter to strengthen themselves both physically and spiritually through using "tree that teaches" in order to face the delicate phases of their apprenticeship. Fasting and isolation in the forest indeed augments dreams and visions that may be scary.

BOX 3

The number of medicinal species is not known for all areas in the world. Schippman et al 2006 reviewed number of medicinal plants known per country. Only 15 countries (Bulgaria, China, France, Hungary, India, Jordan, Korea Rep of, Malaysia, Nepal, Pakistan, Philippines, Srilanka, ThailandUSA, Vietnam), totaling 422 000 of plant species have been analyzed. The average number of plant species in these different countries varies between 7,7 % (Malaysia) to 34,5 % in the Korea Rep of, and an average of 17.1 % . Thus Schippman et al 2006 estimate that 72 000 plant species are used worldwide. USA alone has 2564 known medicinal plant. This study does not show any figure for Africa or from South America which are huge gaps. s Cunningham (1993) shows that the vast majority (70-80%) of people in Africa consult traditional medical practitioners (TMPs) for healthcare and use medicinal plants in large amounts. A very large number of species are involved in domestic trade as well as long distance international trade.

15. NCP 15: Learning and inspiration

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15.1. IPBES Definition

Learning and inspiration: provision, by landscapes, seascapes, habitats or organisms, of opportunities for the development of the capabilities that allow humans to prosper through education, acquisition of knowledge and development of skills for well-being, information, and inspiration for art and technological design (e.g. biomimicry)

15 a: Learning
15 b. Learning - artistic
15 c. Learning - scientific and technological inspiration

15.2. Why is it important?

15.2.1. What are the big environmental issues this pertains to?

The socio-environmental issues are:

1. **Loss of biodiversity and changes in habitats** associated to decreasing access to nature is an overarching environmental issue that decreases our potential to learn from nature

2. **The loss of direct sensorial experiences with nature** is important among poor rural people leaving rural areas for towns and people currently living in towns, where nature is little accessible. Urbanization rates at the global level are increasing and this impoverishes nature contributions to people for learning processes from nature. **Learning directly from nature is crucial to ensure the sustainable use of nature and mutual co-existence of humans and nature.**

3. **Mimicking nature has been used positively by IPLCs and by science**, and proves to be an important potential input for the future in different dimensions of human well-being including agriculture, health, architecture etc. **Scientific may uses of nature (genes, active principles) through human-based engineering** that transform elementary functions of nature (e.g. natural evolutionary processes), can solve some immediate problems of well-being, but may also have important negative impacts on nature and people's well-being at the global level (ex GMO or use of CRISPr and gene drive approaches in non-ethical ways). Substitutes to nature in general need to be highly controlled (e.g. pesticites). This ca be considered as dis-learning from nature.

4. Nature contributes to learning for all dimensions of human well-being from the most material to the most subtle or political and our future is intricately linked to nature. **It is while learning to survive, eat, protect ourselves and explore what is offered by nature that humans have evolved biologically**, starting with the development of tools made of natural materials that have prolonged man's arms, which in turn have had important feedbacks on the development of human brain's cortex (Ambrose 2001).

5. Well-being from nature requires that we learn sustainable processes to develop agroecosystems for food provision, identify natural medicinal products that are essential to health, and understand and benefit of the immaterial gifts of nature to ensure psychological balance as well as develop cultural expressions that contribute to identity and social cohesion.

15.2.2. How does NCP15 play a role?

15a: Learning:

Nature elements that inspire people may be concrete, ephemeral (ex: storms), but generally are elements that stimulate the five senses but which are also embedded into memory, socio-cultural and political set-ups (Nazarea 2016). Learning from and with nature is at the heart of innovations that are strictly based on learning from nature that still ensure humanity's basic and immaterial needs. The major examples are: protection, food, health, art, religion and identity (Atran et al. 2002, Ellen 2002, Descola and Palsson 2002, Descola 2013). Practices that rely on learning from natural processes include:

- **wild food products as well as crops and animal domestication** processes at imbricated scales from local to global levels because of large scale diffusions by humans (Zohary et al 2012, Willcox 2013, Zeder and Hesse 2000);
- **natural medicinal products**, historically and currently used by by IPLCs (Indigenous Peoples and Local Communities) who depend on the latter almost entirely for their health needs (Hamilton 2004, Schippmann et al 2006, WHO 2013, Leaman 2015), based on learning at local levels with large diffusions at global levels;
- **new drugs development by science** using leads from nature medicinal products or which mimic the structure of natural molecules represent 42 to 70 % (the latter for antitumoral drugs) of all drugs that were developed for all diseases at the global level over 30 years (Newman and Cragg 2006), used at global levels;
- **materials protection and shelter**; constructions in many societies still relying on nature-based materials (wood, leaves, thatching, cereal bale etc) and much learning is about their conservation properties;
- **artistic expression**; all musical instruments were initially made and many are still made from plants (wood, seeds) or animal skins (Brémaud 2012). They have in some cases, been substituted. Natural dyes, sponges, pearls are still importantly used and commercialized for their properties and symbolic meanings (Pronzato & Marconi 2008) and have been replaced with substitutes that mimic the latter.
- **nature ecology and development of humanity**; man has been guided by nature to find substances that imply multiple interactions between species, such as honey implying complex knowledge acquisitions and transmissions (Simenel et al 2017, Dounias and Aumeeruddy-Thomas 2017). Studies and findings on multiple species interactions show recognition, especially by IPLCs of the agentivity of non-human species from nature in learning processes (Kirksey 2010, Ogden et al 2013). Among children the importance of direct sensorial experiences with nature is a major learning process (Dounias and Aumeeruddy-Thomas 2017, Beery and Jorgensen 2018). Learning languages to some extent may be inspired by nature (Simenel 2017). The largest ethnolinguistic diversity today is found in areas of high biodiversity (Maffi 2002, Stepp et al 2004).
- **conceptualizing the intangible**; religions are fundamentally based on learning from nature as we can judge by the vast amount of nature elements that are known to be sacred (Verschuuren et al. 2010);

• **maintaining psychological balance**; it has been demonstrated that natural environment is generally beneficial to human well-beings in towns (Cox et al. 2017) and that outdoor recreation activities are important for urban dwellers to foster their well-being (Wood et al. 2013, Beery and Jorgesen 2016, Kuo 2018);

• **making decisions about nature** is an essential part of governance systems in all societies (e.g. Ostrom 2011), and threats upon the latter require multiple policies linked to knowledge on nature required as exemplified by IPBES science_policy dialogue.

15b: Artistic

Nature is symbolized in paintings, engravings, sculptures, theater, dancing, language, songs, poems, rituals, gardening, cookery, cloths or any other forms of artistic cultural expression (Cohen 2005, Fernandez-Gimenez 2015, Chazine et al. 2017, Fuentes 2017, Rapetti et al. 2012). Elaborated artistic expressions used by humans across societies, help to transcend their complex relationships with death and supernatural forces (e.g. use of flowers, food items or amulets to accompany the dead). Nature knowledge are embedded into these practices, their worldviews and conceptualizations of nature (Sieber 1996, Descola & Palsson 2002). Science is also increasingly using artistic expressions to enhance exchanges and explore complex biocultural practices in social-ecological systems including issues of sustainability. This demonstrates a very important aspect of learning through artistic expressions inspired by nature (Polfus et al 2017, Fernandez-Gimenez 2015)

15c. Learning – scientific and technological inspiration

Nature is at the basis of major scientific findings and theories such as the theory of the evolution (Darwin 1859), a theory in biology that underpins many findings including for instance Mendelian theory of genetics (genetic inheritance of traits) which in turn has influenced crop improvement experiments. In other fields such as chemistry, theories and scientific findings use nature elements, such as discovery of the Penicillin by Flemming in 1928, which in turn led to tremendous technological innovations in microscopy. The use of natural products in development of new drugs is based on ethnoscientific findings by IPLCs and scientific knowledge (see details in NCP 14). Pharmaceutical research has used traditional medical products as leads for the development of new drugs (Butler 2004, Richerzhagen 2010, Leaman 2015). These approaches have,in turn, led to technological inventions among others, molecular recombinatory approaches that help mimic natural molecules (Newman and Cragg 2012).

The development of the art of kiting by the Chinese is based on millenaries observations of nature. The dream of flying was realized with the advent of steam motor engines and the discovery of petrol, a natural product which has given way to unprecedented discoveries including plastic. More recently, biomimicry has become a whole field of investigation with a vast number of trials to imitate natural materials from the microscopic levels to the use of nature imitations in architecture and for many other scientific purposes including recently new quests to find sustainable bio-material (Hunter 2017). More generally, different traits of plants, animals and insects in nature have highly inspired many discoveries. Tree architecture with a main trunk and branches is well-known to have inspired ways humans think of genealogies and phylogenies (Hinchliff et al 2015). Helical or coiled structures are very common in biological materials (e.g. proteins and nucleic acids). They have influenced the design of many engines and scientific discoveries. “Nanosprings made of zinc oxide, helical microtubules of graphitic carbon, helical screws and gears, and the helical flying machine dreamed about by Leonardo da Vinci are just a few outputs of the human interest for this shape" (Carpi et al.2010).

The discovery of the microscope in the 18th century led to new levels of appreciation and inspiration by nature organisms. Similarly science and hi-tech tools now uses abstract equations or fractals to access elements of nature. Nanotechnologies are increasingly used to develop biomimicry (Hunter,2017). Scientific experience with nature tends to be increasingly situated within the non-visible and use of sophisticated technologies to mimic nature, reducing the initial natural element that has inspired findings, such as the use of molecules to replace the active principles of a whole plant. The use of information in genes that diverge profoundly from their initial natural purpose, leads to modifications of nature (e.g. GMO), that may affect natural evolutionary processes, or have direct impacts on environment (e.g. Pott et al 2018, Globus and Qimron 2018). Although all these approaches may have major positive impacts on human well-being such as for instance in surgery, there are many debates about potential side effects as well as ethical and power issues (Pott et al. 2018).

15.3. (Co-) production

15.3.1. How is it co-produced? 15 a. b and c

15 a Learning processes (in general)

They are generally based on nature conceptualizations by societies and their cognitive ability to observe, classify and hierarchize nature elements in situ, confronted to direct sensorial approaches with nature since childhood and practices (Beery and Jorgensen 2018, Dounias and Aumeeruddy-Thomas 2017).

Citation: *"I remember the troll forest … the different kinds of smells, the damp moist smell of moss. The pine has a specific smell. And you know the ponds develop a kind of musty stink… »* Beery and Jorgensen 2018.

Direct contact with nature

Direct contact with nature is variable in size and intensity and depends on levels of dependency upon nature and where people live.

In towns. Learning takes place directly in laboratories, zoos, manmade parks, gardens, during travels to areas where nature is present thus involving direct contacts with nature (Kou 2018). People also learn indirectly through, oral and written transmissions, television, internet, museums, artistic expressions, that include nature elements (Casazza et al 2017, Mettelart et al. 2015, Mbaye, 2015)

In natural and rural areas. People who live within forests ecosystems or complex anthropogenic landscapes and have access to a much larger sample of biodiversity. Currently such places are inhabited by IPLCs who either have strong attachments to nature or even perceive themselves at an element of nature (Cuerrier et al. 2015, Reyes-Garcia et al 2016, Garnett et al 2018).

Learning processes include nature classifications and practices (learning through experimenting). Folk classifications by IPLCs establish relatedness between elements of nature based on a diversity of perceptions. The latter may be visible or intangible.

Perceptions and understanding are based on cognitive learning processes as well as direct sensorial interactions linked to sets of practices including material and subtle (e.g. agricultural, artistic, religion, languages)(Berlin et al 1978, Friedberg 1991, Descola & Palsson 2002, Ingold 2002, Sanga and Ortalli 2003, Atran et al. 2002, Descola and Palsson 2002, Friedberg 2007, Simenel 2017). Scientific classifications are based on morphological and visible characteristiques or characeristics such as chemical component that can be analysed (e.g. scientific phylogenies are based on non-directly visible traits, such as genetic linkages between species (Hinchliff et al 2015)

Nature conceptualizations influence humans in artistic expression, education and technological skills or socio-political organizations (Nazarea 2016). Attachment to local customary territory, sense of place, lifestyles including the sacred dimension of nature elements, contribute to learning processes (Verschuuren et al. 2010; Ding et al. 2016; Salmon 2000, Aumeeruddy-Thomas & Lama 2008, Eloy et al. 2015). Dramatic changes (eviction, migration) may lead to dis-learning, losses in knowledge due to socio-cultural disruption (Maffi 2002, Pearce 2016, Ding et al. 2016, Dell'angelo et al. 2017 , Aswani et al 2018).

Indirect experience with nature.

Indirect experience with nature or misunderstanding of the importance of natural processes show tendencies towards the development of potential threats for human well-being.

Numerous studies show that lack of contact with nature, may lead to dis-learning by children if not high levels of stresses among children or adults, hence an increase in development of green spaces in town and environmental classes (Berman et al. 2012).

Departing from nature lessons in agriculture has led to the disproportionate use of chemicals with negative impacts on climate, as well as human health (Altieri & Koohafkan 2008) or the use of GMOs or CRISPRcas biotechnological approaches are seen to have potential threats (Pott et al, 2018, Globus and Qimrom 2017).

15 b. Artistic.

Indigenous peoples and local communities (IPLCs) as well as industrial modern societies across the world develop signs and symbols in ornaments, ritual masks, tools, and clothes.., based on inspiration from nature resources. This is illustrated in native and modern folk art at the global level. Folk art simultaneously use materials from nature as basic material (wood, ivory, animal's teeth, horns, bird feathers, natural dyes etc) or as symbols of human-nature cultural linkages (Bay 2017, Argenti 2007). Folk art among IPLCs have multiple known values including aesthetic, identity, sacred, sexual etc. (Forestier et al. 2008).

Artistic representations of Nature vary across time and space. In Europe, for example, romanticized Renaissance paintings of landscapes where Man is a separate element of Nature, observing the latter as an outsider (e.g. Rapetti et al. 2012) differs from modern impressionist paintings that build on a direct immersion of the painter into the landscape (Athanassoglou-Kallmyer 2015, Bernardi and Ferlier-Bouat 2017). Much of ancient art from Africa and other continents have been gradually integrated into more global spheres through major art markets (museums and personal collections) even though there are many criticisms about their extraction from their primary purposes (Jewsiewicki 1996). Museums and exhibitions however play a major role through conveying the aesthetic messages of these vanishing patrimony linking human societies to nature (Sieber 1996). At local levels, development of a wide economy of native and indigenous folk art may also be instrumental to convey messages beyond localities (Ex Indonesian art, and Papua New Guinea sculptures and textiles).

15 c. In science.

The discovery of the microscope in the 18th century led to new levels of appreciation and inspiration by nature organisms including major scientific discoveries such as the bacteria and major ways to face health problems such as antibiotics. Science has been involved in mimicking nature and also experimenting with nature including all animals and plants used in laboratories to test scientific experiments. Chemistry plays a crucial role in creating synthetic analogues of bio-macromolecular structures (Messager et al. 2016). Major scientific learnings regarding nature's structure tends to use learnings from nature to transform nature such as the use of CRISPR (Globus and Qimrom 2017).

Summary bullet list of how this NCP is produced:

- ***1. Direct***: Co-existence between people and natural or anthropogenic habitats / landscapes that favor sensorial experience with nature since childhood contribute to learning processes that are crucial to human well-being (livelihood needs, artistic expression and technological innovations). Folk art, songs, textiles, objects and any artistic expression that improve inspiration from nature or anthropogenic landscapes, are likely to improve livelihood and inspire a variety of learnings from nature including nature-based practices, such as agroecological practices or producing new nature-based materials.
- **2. Direct:** Greening projects in towns and increased urban and peri-urban connections; increased access for people living in artificialized areas to natural areas or anthropogenic landscapes (e.g. nature-based tourism in protected areas or parks, natural food and medicines not directly available in the immediate environment). Children's and other professionals' access to educational programs that favor contacts with nature, improves their understanding of complex issues and capacity to learn in general. Research conducted in laboratories and research findings using nature-based products show the extent of learning from nature.
- ***3* Indirect :** Indirect access to nature through audiovisual products (songs, photos, films, museums) and other media (internet widely distributed at regional and global levels); other forms of artistic expression linked to nature-based learning processes indirectly co-produce learning processes. Existence of artistic projects, museums that exhibit human-nature linkages and nature films accessible on T.V. and or internet develop learning and inspirational processes.
- ***4 Indirect:*** Scientific experiences mimicking nature and scientific experience inspired by nature are crucial for the well-being of humanity (e.g. new drugs based on natural medicinal products, technological findings that mimic nature) while scientific learnings from nature that use technologies to distort nature may disrupt human well-being.

15.3.1.1. Links to other NCPS

- *note specific links as appropriate, otherwise delete*
- *NCP2 – pollination* – Learning from pollinators is as old as humanity with the domestication of bees which is one of the earliest animal that Man has started to bring into the domus. Manipulation of the pollination of dioicious trees such as Date Palm and Mediterranean Fig (Ficus carica) also dates back to Mesopotamien period. These examples show the extent of how people have been learning from pollinators to access staple resources and well-being.
- *NCP3 – air quality* – Air quality is associated to specific places. Humans are very sensitive to air quality because one can feel the goodness of air and less polluted places; more natural places are known to be places required by human populations to make them feel well, especially for people living in town; nature elements even in town such as trees in towns may be the source of much inspiration
- NCP4 – climate – Nature's contribution to learning is inherently linked to climate because many nature-based human activities rely upon climatic conditions, such as agriculture and pastoralism, wild food and medicinal products, pollination etc…Learning how to regulate climate impact especial regarding hazards has represented an important learning process for humanity
- *NCP5 – ocean acidification* – Fisherman and other stakeholders who are highly dependant upon ocean and seas are very sensitive to changes in the nature of ocean water quality and either IPLCs or conventional Ffshermen have their own indicators that help them assess the quality of the sea.
- *NCP6 – water quantity* – A large set of knowledge on water quantity is directly related to learning processes from nature as this has led for instance to a large set of technological innovations such as water wheels, a diversity of irrigation and water conservation systems, including dweue collection systems.
- *NCP7 – water quality – Same as for water quality, but also relates directly to human and domestic animal health. Indicators of water quality used by IPLCs and Scientific approaches are plentiful and relate to historical learning processesl.*
- *NCP8 – soils* – Same as for water quality and water quantity…Learning about the nature of good and bad soils is a prerequisite to all farming approaches.
- *NCP9 – hazards* – Societies throughout the world learn from hazards, because it is necessary to try and predict the latter such as for volcanoes or cyclones. Hazards as a form of natural phenomenon also therefore implies learning processes, including in development of appropriate architecture, protecting watersheds and seashores etc.
- *NCP10 – pests* – As any other element of biodiversity, humans also learn from pests , generally because there is a need to control the latter.
- *NCP11 – energy* – All types of nature-based energy implies also learning processes, such as regarding fire, but also biogas, solar etc.
- *NCP12 – food* – Food is at the heart of many learning processes, both through tasting which as such is a form of learning, but also because food is in the middle of many social exchanges.
- *NCP13* – materials – same as food, but other materials such as wood, require learning about wood quality, flowers, about their phenology and also what people like etc…and regarding pets, for instance dogs, they have been under domestication process for almost 20 000 years which also has implied major learning processes

• *NCP16* – experiences – Learning from nature is highly connected to direct sensorial experiences of all types and is a perquisite to develop learning processes that do not distort natural processes.

• *NCP17* - identities –Learning is linked to the sense of place that is closely connected to cultural identity and evictions

15.3.2. How is it measured?

15.3.2.1. Indicators of NCP production or co-production

1. Direct:

- Locally co-produced anthropogenic landscapes, agroecosystems, artistic productions form the basis of learning processes developed by a large diversity of cultural groups (known as IPLCs) who are inspired by nature in all dimensions of everyday life from the most material (construction, food and medicine) to the most immaterial (religion) or for organizational and decision making purposes;

The use of mimicry of natural processes to build agroecosystems such as agroforestry that includes tree and forest ecological dynamics shows the extent of areas across the world that benefit of such approaches. The extent of these co-produced areas could be used as a measure of systems where learning from nature is highly present such as agroforestry or shifting cultivation (Zomer et al. 2009, Heinimann et al. 2017). Different maps available in litterature [Map of distribution of agroforestry systems at a global level (Zomer et al. 2009 http://www.worldagroforestry.org/downloads/Publications/PDFS/WP16263.pdf, Map of distribution in shifting cutivation systems,Heinimann et al (2017)]

Sacred and recreational approaches of nature procure represent major learning processes [e.g. Map of distribution of sacred landscapes at the global level, Verschuuren et al. (2010)], represent areas where learning processes and inspiration from nature are potentially very high. The diversity of types of sacred sites and number of sites across the planet, shows the level of inspiration of nature for religions. The number of people visiting some sacred areas and their classification as UNESCO sites or other heritage sites could also be used for measuring the level of learning from nature through spiritual experiences (see NCP 16). The very high rate of visits to protected areas, also indicate potential learning processes from nature by urban dwellers (Balmford et al. 2015)

- The important use of nature symbols and materials in art is not quantifiable, but shown by a large set of local studies, museums catalogues (Sieber 1996, Polfus et al 2017, Rapetti et al. 2012) and figures of museum frequentations rates.

-There is an overlap between areas of high biodiversity and ethnic diversity that has been identified (Maffi 2002, Sutherland 2003, Pretty et al 2006, Turvey et al.2014). These areas correspond to high plants species richness, generally used as a proxy for overall species biodiversity in approaches for identifying hotspots of biodiversity. Stepp et al. (2004), also show correlations between linguistic diversity and plant species richness. We use an updated map (Figure 8), prepared by IPBES, as a proxy to show the convergence at the global level between cultural diversity (identified here by areas of origin of languages) with areas of high species richness (we do not consider which of these languages have been lost) where we consider that learning processes with and from nature has been over time in these areas also high. This series of maps show 25% of overlay in hotspots of species richness and distribution of language origins richness, a result which corroborates previous studies by Maffi (2002) and Stepp et al (2004). We use updated data calculated from the latest version of IUCN 2017 (for Mammals, Amphibians, and some of Reptiles), Birdlife International 2017 (for Birds), Collen et al 2014 (for freshwater), and Kreft et al 2007 (for vascular plants).

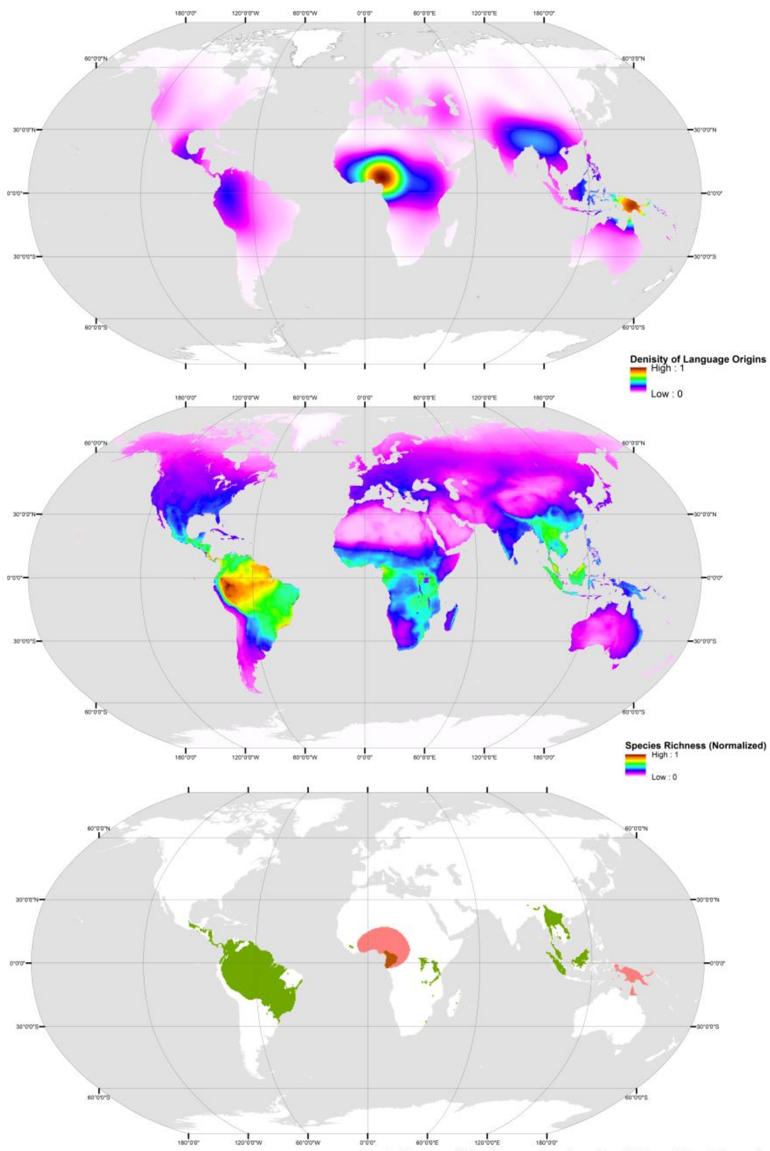

Figure 8: **top** the kernel density of language origin points [calculated with points obtained from the Glottolog database, See http://glottolog.org/ for more information], **middle** the relative richness of terrestrial species, standardized equally weighed across

clades [calculated based on IUCN redlist spatial data 2017, Birdlife International 2017, Collen et al. 2014, and Kreft and Jetz 2007], **bottom** the top 25% of area with high density of language origins (in red) and the top 25% of area with high relative richness (in green). Courtesy Aidin Niami (IPBES Core data).

4. Indirect: There is no way of assessing indirect experiences of learning from nature. For example there are numerous scientific experiences mimicking nature which provide indirect experience from nature. Scientific experience inspired by nature are also plentiful and experiences that use nature as a source of inspiration as well. Specific reviews on specific natural traits used in science are available such as the use of the imitation of skin in soft robotics for instance used in surgeory.

15.3.3. Trends in Co-Production

Trends to revitalize nature learning processes or improve proximity to nature, such as re-discovering or innovations in agroecological practices, recognition of biodiversity-rich agroecosystems previously disregarded by modern agricultural policies, are now gaining new recognition (Michon et al. 2011, Aumeeruddy-Thomas et al, 2012, Lescourret et al 2015). Parallel trends exist in the use of botanical medicines or nature-based tourism (Wolff et al 2017). Techniques such as agroforestry, or fire management and complex biodiversity-rich mosaics (Haijan-Foorooshani et al. 2014, Iverson et al. 2014, Cunningham et al. 2013), that are widely spread throughout the tropics, dry tropical savannahs and Mediterranean regions are being reinvented and tested (Mollard and Walter 2008; Altieri et al. 2015). Agroforestry (Janzen 1986, Michon 2015) or the use of elevated mounds in large flooded plains for agriculture (McKey 2014, Mckey et al. 2016) show learning mimic of forest ecological dynamics for agroforestry and naturally self-organized natural mounds in flooded plains.

Trends towards improving contacts with nature in towns include the increasing importance of the use of organic food, as people are more and more aware of the negative impacts of chemicals in industrial food and the creation of urban-rural producer networks (Rover et al. 2016). There is also an increased interest in community gardens in towns in the global North (Gregory et al 2016), development of urban- rural networks or humanitarian approaches in peri-urban areas such as in South African Townships to develop organic food farms for urban areas (Dyer et al. 2015).

Forms of co- production between people and nature such as landscapes are now recognized beyond their area of production at the state level and increasingly at the global level (Cultural Landscapes UNESCO, GIAH sites FAO, List of Intangible Heritage UNESCO). These global heritage sites are significant sources of inspiration because they integrate holistic man–nature relationships within areas that are still being managed by local social groups. National parks and the high degree of visits by urban people are also an indicator of the high need for people living in more artificialized environments to reconnect with nature that constitutes the basis for learning processes (Balmford et al. 2015; Cox et al. 2017; Wolff et al. 2017).

15.3.3.1. General (across all units of analysis)

15 a: Trends in learning

Trends of how people are inspired or learn from nature depends on their **direct experience with nature**. Due to overall biodiversity loss (Barnosky et al 2011, Ceballos et al. 2015) it is expected that people, globally, will have less access to biodiversity, although increased human mobility has increased access of a portion of urban people for example to protected areas (Wolff et al 2017). However, it is not yet demonstrated to what extent mass tourism of people visiting protected areas affect effectively their learning process from nature. Among new ways of learning, a global restoration movement of biodiversity promotes approaches involving a large range of stakeholders from local to global levels (Chazdon et al 2017).

Socio- ecological well-being is a crucial factor affecting learning processes.

In rural areas, people who suffer of high poverty, political conflicts, climatic constraints, lack of land tenure over customary lands are less able to learn and be inspired by nature and are likely to migrate in the absence of political support and development schemes (Ding et al. 2016, Dell'angelo et al 2017). NCPs are also highly dependent upon cultural contexts and worldviews (Diaz et al 2018) as well as people's vision of well-being which may vary hugely (Sterling et al 2017). In the high Nepal Himalayas where people are extremely poor, lack of basic modern health care facilities, specialist healers (amchi) have a very high knowledge of medicinal plants (more than 300 species known and used) and are still learning from nature in order to face issues of resource scarcity (Aumeeruddy-Thomas & Lama 2008; Lama et al. 2001).

Many groups among IPLCS tend to revive knowledge and rituals that ensure continual linkages with nature and supernatural forces that reside in the latter within localities (Argenti 2007, Aumeeruddy-Thomas & Lama 2008, IPBES Montreal Dialogue report IPBES Core). They may also engage in conservation programs that associate such practices to improved conservation of biodiversity (Fernández-Llamazares & Cabeza 2017).The status of IPLCs also shows some signs of a growing recognition within global governance systems (UN, UNESCO, CBD, IPBES) and in some cases at national levels (Rodrigues 2015). There is also a notable interest in research to understand IPLCs perceptions of nature to improve sustainable management of BES (IPBES Dialogue Workshop reports). Learning processes by IPLCs through increased exchanges between IPLCs within such fora affects positively their learning process through sharing and exchanges. Trends of overall loss of ILK is however demonstrated (Aswani et al 208)). Leaving rural territories may also sometimes represent the own choice of many people in rural areas including IPLCs. Indeed, despite the idealized vision that we may have of indigenous peoples living in close proximity with nature, they may gain in well-being through being in more artificialized areas (Levang et al 2005)

<u>Food and agroecosystems</u>: There is evidence that people living in contact with agroecosystems with a high level of diversity (often less high than in natural set ups), are still able to learn from nature as shown by the very large set of cultural landscapes where crop landraces have been selected and are still under selection. A large set of other products are produced in human-nature co-constructed agroecosystems (Mollard & Walter 2008) Global International Agricultural Heritage sites of the FAO which are samples of these agroecosystems are very good indicators of the importance of such sites for learning http://www.fao.org/giahs/become-a-giahs/en/. New trends in agriculture include an increased interest for agroecology, supported by different policies at regional and global levels, but also urban and peri-urban agriculture (Orsini et al 2013). Right at the opposite to this trend, major transformations in natural processes, with the use of GMO and CRISPR is

inevitably developing with a trend that is opposite to natural processes. Debates as whether such solutions are safe or ethical are underway (Globus and Qimron 2017).

Medicinal plants richness: although 15 000 species are potentially threatened due to overall threats of extinction in plant biodiversity, there is also evidence that secondary forest species may also be rich in active principles, many of which are still unknown . Medicinal species originally used as wild resources may also be domesticated (Schippman et al 2006, Simons and Leakey 2004). Thus the capacity to learn from nature is not dependent upon biodiversity richness alone, but access to some level of diversity that may help restorations and transformations. The threshold of biodiversity richness that would disrupt learning processes from nature is difficult to establish. This threshold is also probably highly dependent on the sense of place and belonging to socio-ecological systems and cultural keystone landscapes.

In urban areas, economic status of different groups affects their capacity to learn. Inequitable access of people to nature is well-known in cities (e.g. Tang 2017, Cox et al. 2017). Since 2007, more than half of the world populations live in cities, a trend which is increasing, and learning processes involving nature will slowly decrease if new solutions are not found (Orsini et al 2013). Children in towns increasingly are lead to re-establish contacts with nature through environmental courses (Prévot et al. 2018). Green spaces, botanical gardens and the greening of towns in general including botanical gardens and zoos that may include environmental and artistic programs developed outdoor are becoming increasingly important to re-instill nature elements within urban areas and heal human depressions (Berman et al. 2012). A large diversity of approaches however show that urbanized areas tend to recreate small spaces of nature such as green spaces which have a positive impact on urban societies wellbeing, although urban planning show major issues of inequity (Hodson et al. 2017, Tang 2017). Educational tools are now widely used to help urban people reconnect with nature, such as Green classes for children (Hodson et al. 2017) or new artistic experiences (e.g. Casazza et al 2017). People living in towns tend to reconstruct connectedness with nature with an increase in trends of use of natural products from long distance trade or through moving temporarily to natural areas (Balmford et al 2015, Wolff et al. 2017). Balmford et al. (2015), estimate that the totality of the world's protected areas are visited by 8 billion visitors per year. This trend has been increasing over the past decade. Food and natural medicines are probably the most direct experience with nature and other non-human species that city dwellers can experience. The demand for exotic food products, such as cacao and soyabean, including for biofuel and as feed for animals in rich countries, have detrimental effects in source areas creating competitions between crop areas for export and for local subsistence and food security (Wolff et al. 2017). Although people in source areas may have some immediate economic returns such as through harvesting of medicinal plants benefits remain very low had such pressure has a major impact on biodiversity loss (Cunningham 2001, Wolff et al. 2017, Leaman 2015) with potential consequences on well-being locally and at global level.

Experiences in urban areas have changed to an indirect one, through the generalized use of nature photos and films as well as access to nature through internet. This is exemplified by the huge economy of Nature films (The Telegraph 2016), and a diversity of media and publicity which use images of nature.

15 b Trends in learning artistic.

Artists performing Indigenous art that are recognized globally, such as Artists of Papua New Guinea Art are generally urban dwellers in their country (see for example:

https://en.wikipedia.org/wiki/Papua_New_Guinean_art) and perform at the global level. Locally, cultural groups such as those living along the river Sepik, are well-known to still produce nature-based folk art which may later be incorporated into larger markets, facilitated by global labels such as Global Heritage sites. Folk art in general of people living close to nature is finding new markets with the increase of nature-based tourisms. In some cases however such as the trade of animal wood sculptures in East Africa, these new industries based on local know-how or derived from local community initiatives may place major threats on resources (Cunningham et al. 2005). Although this may lead to commoditization and distortion of the value of the latter to fit with the requirements of tourists, changing its holistic and sometimes spiritual value into a strictly monetary value, some aspects of local cultures may remain while representing a way for the survival of local economies (Cohen 2005).

Inspiration and learning from nature probably finds its finest expression in artistic designs that use nature as a base and which contribute to human well-being and in cultural heritage such as cooking practices. This also includes architecture using natural materials and dyes etc., as well as clothing. There is an increasing trend in architecture to recover practices deriving from what is known as vernacular architecture, using natural material.

The area in which artistic learning is probably the most prominently changing is probably that of nature film makers and photographers, showing a quest for nature that is rarely immediately accessible, but in high demand at a global level. Despite some trends showing that artistic learning may still be inspired by nature, it is very likely that in paintings, poems, songs, dances etc, humans living in increasingly artificial contexts will lose touch with nature in artistic expressions, as shown for instance in Street Art. It is expected that artistic expressions using nature as a principal source of inspiration will still remain within the hands of people who have recently left rural and or natural areas, or cultural landscapes and who can access global markets to perpetuate artistic expressions of nature that still have strong linkages with nature.

Summary of NCP trends

- ***Trend*** (& why):

1) Direct: 15: Learning Decreasing

Direct linkages of IPLC to local territories in areas where they depend entirely upon nature is likely to be decreasing because of: a. Lack of recognition of land tenure; b. conflicts for land use related to demands at the global level of goods and services to satisfy desires for well-being rather than basic needs (e.g. oil palm, soya, cacao, cotton etc…); c. knowledge and language loss ; d. changing lifestyles

15b: Learning artistic is decreasing in areas where people are living in close proximity to nature unless nature-based tourism is available or simply tourism circuits do not destroy vernacular architecture and favor perpetuation of local art, and in some cases innovations… This has been the case in specific areas such as Bali where artistic expression has been “ boosted “ by tourism, although there is much debate about authenticity.

2) Indirect: Increasing

Rights of IPLCs likely to increase with positive impacts on lifestyles, but figures of trends missing on how this may increase learning. Movements of identity by Indigenous groups may lead to some revival of indigenous art tat is based on natural resources or use nature as signs or symbols.

Some potential positive feedbacks take place in cases where demands from urban areas create innovations in source areas such as development of peri-urban agroecological services, or extension of agroecosystems in rural areas (such as biodiversity – rich Cocoa or Coffee agroforestry systems, Acai palm agroforestry in Brazil) (Padoch et al. 2008).

This marks a transition of urban economies to decrease long distance trade and economies towards local market circuits. Equitable and or organic products and labels likely to increase and improve learning process from nature but today still largely insufficient.

Direct: Increasing (rich populations) and decreasing for the poor. Human mobility to access different natural habitats is increasing. At global levels: trends of visits for outdoor activities. At the opposite, human migrants are leaving natural areas due to poverty, wars and conflicts, or issues of rights of access and tenure which decrease in learning processes from nature especially for IPLCs.

Indirect access to natural products from natural habitats (e.g. natural products consumed in towns, food, medicine, materials for architecture, horticulture) typically related to rich urban dwellers. Case study and review available by Wolff et al. 2017. This trend is increasing at the expense of people's well-being in source areas, although some feedback on innovations in relation to demands in source areas may show that this trend may also improve well-being in those areas. Case studies showing success i.e increased management of natural resources in source areas (Padoch et al. 2008), domestication of some medicinal species, such as Prunus Africana as a result of resource scarcity and high international demand (Simons and Leakey 2004), establishment of new urban-rural networks for food production leading to rehabilitation of small scale organic agricultural systems based learning processes from nature.

Spatial variance (& why):

For all measures : There is a significant variance between developing countries, where people globally evaluated as poor still depend very heavily on nature to fulfill their basic needs as well as their well-being and the global north as well as emergent countries, where urban dwellers are more dependent on goods and services rather than direct provisioning.

- ***Degree of certainty*** (& why): the degree of certainty is average, because data is not available homogeneously for all social groups across the planet and or all biomes.

15.4. Impacts on good quality of life

Good quality of life is known to be highly variable from one socio-cultural set up to another because people value nature very differently (Pascual et al. 2017) and consequently ways of considering well-being in relation to Nature (Bennett et al. 2015). Thus learning processes and impact on good quality of life also depends upon different attitudes to well-being and factors that vary across cultures. Several studies differentiate between basic needs and desires, i.e. needs that are beyond basic food, health, shelter and protection needs (Narayan et al. 1999, Wolff et al 2017). All societies rely upon social welfare that is also dependent upon institutions, exchange networks and power systems that may rely upon nature for their well-being (Brondizio et al. 2009). In urban areas for instance, green spaces and or outdoor recreational activities to visit natural sites, participate to social cohesion and therefore learning processes(Wood et al

2013). New learning processes relating to nature such as citizen sciences are developing (e.g. Carpaneto et al.2017)

Capacity to learn from nature for well-being is not necessarily correlated to being rich or poor because people who depend almost entirely on natural resources for their subsistence such as Indigenous Peoples and Local Communities, although classified among the global poor according to global norms (Narayan et al. 1999) can develop very high knowledge of natural processes and of biodiversity. They in particular have other criteria to define well-being (UNU-IAS , 2014).). Their well-being is affected if they are denied access to their lands or loose resources such as medicinal resources that are essential for their health, agricultural lands that are essential for local food provisioning.

In urban area the absence of nature or highly artificial lifestyles, especially those of people living in large cities that demonstrate the prominent role of access to nature in different forms (recreational, cultural, food, health, cosmetic) and thus an ever increasing demand for nature for developing good quality of life.

Learning from nature contributes to GQL (Good Quality of Life) at the global level through provision of diverse materials, medicines, artistic inspiration etc. At sectorial levels, impacts on GQL may highly vary.

In the health sector new drugs based on NMPs have to have major positive impacts on major human diseases at the global level (Newman and Cragg 2012). Natural Medicinal Products identified by ILK providing health care to 60-80 % of the global population (WHO 2013). This also contributes to the global GQL through providing cues for discovering new drugs, and materials to feed increasingly large international markets meant for improving GQL in large urbanized areas (Wolff et al 2017). Figures are available regarding trade in NMPs at global level (see NCP14)

In the agricultural sector, learning from nature has contributed to GQL at the global level, through domestication processes of appropriate plants and animals for human use**.** Industrialization and high use of chemicals, disregarding learnings from nature, have substituted nature and ecosystemic processes, leading to dramatic impacts at the global level on climate change, pollinators and health (cf. NCP 2 and 12). Negative impacts on biodiversity and health are demonstrated in the regional IPBES reports. Large tracts of traditional agroforestry and shifting cultivation systems still provide large yields (global figures not available) for a large proportion of the world population (cf. Map, Zomer et al. 2009). Regional policies (e.g. Europe) are currently favoring the development of agroforestry and agroecology development (Wezel et al. 2018). Variance is high at the global regarding these trends. FAO's recognition importance of family farming and developed the GIAHS network http://www.fao.org/giahs/giahsaroundtheworld/en/, but large tracts of biodiversity-rich landscapes including agricultural systems that contribute locally to GQL receive little support as shown by figures regarding shifting cultivation (Heinimann et al 2017). The estimate of área under shifting cultivation landscapes covers 280 million hectares worldwide, including both cultivated fields and fallows. This area is likely to decrease drastically at the global level in the coming two decades raising issues of livelihood security (Heinimann ibid). Small-scale farming provides to the world, products that are traded at the global level such as cacao, coffee, tea, spices, quinoa, olive oil, cosmetics, besides contributing to many NCPs (e.g. NCP pollination). These products are commodities that increase GQL at the global level (Wolff et al 2017).

In the recreational and educational sector, the system of protected areas at the global level provides urban dwellers with opportunities to learn and being inspired from nature (Balmford et al 2015, Wolff et al 2017). Green classes and urban green belts are acquiring more attention and realization mainly in developing countries.

In the artistic sector, nature has contributed fundamentally to all artistic dimensions, material and immaterial, such as musical instruments (all initially made of natural products), poetic inspiration, architecture etc. providing invaluable GQL at the global level (e.g.Rapetti et al. 2012). Museum frequentations rates are a possible indicator of the importance of art to global GQL (e.g. 2016: Louvre, Paris, 7.4 M visitors, British Museum 6.4 M visitors) https://fr.statista.com/statistiques/477102/frequentation-touristique-des-musees-europe/.

Religion The network of natural sacred sites at the global level is an indicator of the extent of impact of learning from nature to GQL (Map, Verschuuren et al. 2010).

15.4.1. How do we measure nature contributions to GQL?

We may use a diversity of measures or indicators:

-Figures of nature-based tourism available in literature can be used as a proxy showing the extent of this link established with nature (Balmford et al 2015, Wolff et al. 2013).

Le Improvement of children and adults well-being when engaging in nature programs as shown by a diversity of studies (Berman et al. 2012, Gregory et al. 2016, Cazazza et al. 2017, Hodson et al. 2017, Kuo et al 2018).

-Access to products from natural habitats (e.g. natural products consumed in towns, medicines, food but also materials for architecture, horticulture, home gardens, natural cosmetics etc.) (Wolff et al 2017), trade figures of botanical medicines used in town (Schippmann et al 2006).

-Figures available for new drugs show that 40 - 60. % of new drugs are based on leads from natural products or are nature mimics (Newman and Grag 2012)

-Access to nature in television programs, shown by the market represented by environmental films such as BBC Planet Earth (The Telegraph 2016)

Cases of artistic expression linked to nature-based learning can be measured by level of Museum frequentations

15.5. Compiled Status and trends of co-production and impact in GQL

	Potential Nature's Contributions	**Output of the joint production**	**Impact on good quality of life**
Indicator	Biodiversity intactness index (for plants and vertebrates) B) In situ genetic resources of interest to science and ex situ gene banks or genetic and or chemical related informations.	A) Ability of learning through direct proximity of people with nature in biodiversity-rich landscapes or agroecosystems; Indicator: IPBES Core/ Aidin Niamir: overlay of linguistic diversity and biodiversity intactness index. B) Elements (parts) of nature used in scientific experiments, from species to genes and their continued natural functional and evolutionary roles (Proxy: Parts or	Human well-being: care, mental health, cultural security, life-satisfaction Diversity and economic value of bioinspired production

		fragments of nature used in scientific experiments)	
Trend During the last 50 years: 2 = Major increase (>20%) 1 = Increase (5% to 20%) 0 = No change (-5% to 5%) -1 = Decrease (-20% to -5%) -2 = Major decrease (< -20%)	: -2 An overall global decrease in biodiversity (B): +2 due to increase in human asset/ capacity to extract information from nature, or fragments of nature (e.g. genes)	(A): - 2 Learning from nature by global population living in proximity to nature decreasing due to high rate of urbanization and large portions of poor urban dwellers having little capacity to travel to natural recreational areas. (B)-2: Use of nature elements by science with consideration of their functional and evolutionary roles as opposed to fragments of nature and information extracted from nature processes	A); -2: Life satisfaction globally decreasing due to conflicts, urbanization, loss of cultural identity and linkages to nature and lands, diseases, lack of food security or obesity and large scale migrations in large urbanized areas where strong inequity prevails. B): °+ 2 Overall value of bio-inspired goods increasing although concentrated within few very large industries (Richerzhagen 2011).
Spatial variance 3 = opposite trends in different regions 2 = same directional trends in different regions but of contrasting magnitude 1 = similar trends all over the world	(A): 2 (B)3	(A) 3: Opposite trends between people living in proximity with nature and people in urbanized settlements.	+ 2: similar trends both in rural areas and in urbanized areas. (B) 3:Impacts are diverse among user groups.
Variance across social groups 3 = opposite trends for different groups 2 = same directional trends for different groups but contrasting magnitudes 1 = similar trends for all social groups	NA	(A) 3: Opposite trends between people living in proximity with nature and people in urbanized settlements. (B) : Co-production is concentrated in scientific institutions the results of which is co-produced by a few large industries. A large majority of user groups do not participate to this joint production	A) : 2 Level of awareness, care, mental health, cultural security, life-satisfaction are globally decreasing (B): 3 Impacto on GQL of bioinspired goods are not equally accesible to all user groups. Modern conventional medicines are for example little accesible to user groups living in close proximity with nature.
Degree of certainty 4 = Well established: Robust quantity and quality of evidence & High level of agreement 3 = Established but incomplete: Low quantity and quality of evidence & High level of agreement 2 = Unresolved: Robust quantity and quality of evidence & Low level of agreement 1 = Inconclusive: Low quantity and quality of evidence & Low level of agreement	(A): 3 B): 3	(A): 3 B): 3	(A): 3 (B): 3

SUMMARY: explanations of the above table

A) **Potential:** Learning processes among children in IPLC communities as well as with general populations of adults in towns show the importance of direct sensorial experiences with nature (Dounias and Aumeeruddy-Thomas 2017, Cox et al 2017).

Learning from nature ensures humanity's basic and immaterial needs (material protection, food, health, communication, culture, religion etc.) (Ellen 2002, Descola 2013). Learning processes among children in IPLC communities as well as with general populations of adults in towns show the importance of direct sensorial experiences with nature (Dounias and Aumeeruddy-Thomas 2017, Cox et al 2017). Learning languages can be inspired by nature (Simenel 2017). The largest ethnolinguistic diversity, a major trait of cultural diversity is found today in areas of high biodiversity (Maffi 2002, Stepp et al. 2004). This is further demonstrated by Indigenous Peoples lifestyles that depend entirely on learning from nature (customary lands covering 38 million km^2 i.e. over a quarter of the world's land surface), and their ability to protect nature (40% of all terrestrial protected areas and ecologically intact landscapes) (Garnett et al 2018). Furthermore, IPLCs recognize agentivity of non-human species in enabling learning processes (Kirksey 2010, Ogden et al. 2013). Over 70% of the global human population is predicted to live in cities within 30 years (WHO, 2016a) with very low levels of proximity to nature and consequently, urbanization as such being considered as the most significant health issues of the 21st century (WHO,2016b). Urban dwellers are known to increasingly travel to natural areas for recreation (Wolff et al. 2017), and use high amounts of natural products for their health, home care etc. (Hamilton 2004). They remotely access nature through books, T.V., Internet etc. Urban areas decrease proximity between people and nature (not considering efforts for re-greening towns that is underway, or ecological transitions in towns) but stresses and health problems may occur due to lack of proximity to nature, inclusing through unequal access to nature in towns(Cox et al. 2017, Tang et al XXX)). Urbanization thus contributes negatively to capacity for learning from Nature.

B) Nature's contribution to science: Nature mimicry is at the origin of many scientific findings: chemical dyes and colors (Galan 2007), biomimicry for medicinal drugs (Newman and Crag 2012), imitation of natural microscopic elements, nature imitations in architecture and sustainable bio-material (Hunter 2017). Nature patterns are used to develop thinking processes (e.g., phylogenetic trees) (Hinchliff et al. 2015). The discovery of the microscope in the 18^{th} century led to new levels of appreciation and inspiration by invisible nature organisms. Similarly, science and hi-tech tools now uses abstract equations or fractals to access elements of nature or nanotechnologies to develop biomimicry (Hunter 2017). Manipulations of fragmented parts or elements extracted from their living natural environment, such as genes, lead to transform nature such as with GMOs. While this may have positive impacts to feed people or produce now materialsmajor questions regarding their negative impacts on the environment (Pott et al 2018) . The use of gene drive techniques already applied on mosquitoes, but not yet released in situ, are expected to have major positive impacts on human health (Ganz et al. 2015, Hammond et al XXX), but such approaches are under debate due to major ethical concerns, as well as potential hybridization with other species thus disrupting fragile ecological equilibrium.

Trends:

(A) Several studies show the congruence between loss of linguistic diversity and species diversity, although evolutionary processes of linguistic and biodiversity are not strictly connected (Turvey et al. 2014). It is well established that there is an overall loss at the global level of linguistic diversity (Maffi 2002, Stepp et al. 2004). Current loss of ethnoecological knowledge of nature is also acknowledged (Aswani et al. 2018). Loss of cultural diversity affects Nature's Contributions to learning processes with major changes in knowledge transgenerational transmissions (Dounias and Aumeeruddy-Thomas 2017). Although a percentage of urban dwellers can access nature through travels for recreation, the global rate of urbanization (more than 50% of the world's population is living in towns) is rising exponentially (United Nations, 2014). There are indications that nature is becoming a rare elements in major cartoons watched by children (Julliard et al. 2014) and that two dimensional images of nature through internet or T.V. cannot replace direct learning processes from nature. Cultural expression is faced with disconnection from nature due to the global rate of urbanization, although some artists who have recently left lifestyles connected to nature, may still include in their cultural expressions people's linkages to nature. e.g. http://www.drokpa.org/tennor.html. The digital age is likely to facilitate connections between nature and culture (Liang 2009, Callenglish, 2018 forthcoming). Folk art at the global level is increasingly designed for tourists and may lose some level of identity, but global demand also represents an opportunity for developing local economies. Artistic expression in town relies very little on learning from nature, except for few experiences in land art by a few artists.

Since the 18th century, with the discovery of the microscope as well as the importance of microorganisms for human welfare (antibiotics), science has been increasingly using smaller fragments of nature. The use of genes and synthetic molecules have been included into major industrial processes, such as agrodiversity to increase crop yields, bio-inspired medicines. Science has thus driven away quite significantly from examining nature processes, to manipulating nature processes through extracting fragments of nature (genes for example). The trend of nature transformation has increased exponentially over the last decade with major discoveries including sophisticated techniques for transgene manipulations (e.g.CRISPR_Cas, gene-drive approaches) (Ganz et al. 2015, Hammond et al 2017. The extent and capacity of science to transform nature is thus embedded in learning processes, that are only attainable by very few specialists, who can however change very large tracts of nature, due to potential impact of manipulated plants, fungi and animals that may be produced on other species.

15.5.1. Co-production by Units of Analysis (if available/relevant)

Narrative review based on literature (500-2000 words). We could use habitat loss or regeneration as a proxy to see the trends per unit of analysis, but we finally did not use it due to lack of time to cross-check evidences between loss of access to the different units of analysis and the effective loss of habitats.

Not relevant per UoA because data not available

Summary bullet list of NCP (co-) production trends (your assessment and rationale, briefly):

- **Trend** (& why):
- **Spatial variance** (& why):
- **Degree of certainty** (& why):

15.5.1.1. co- production UoA Summary Table

Unit of Analysis	Direction of arrow	Rationale/ justification for why you think this trend is happening
1. Tropical and subtropical dry and humid forests	Decreasing -2	Biodiversity loss : more than 20 %
2. Temperate and boreal forests and woodlands	Decreasing -1	Overall forest cover increasing, connectedness of people and nature decreasing due to life styles. Less increase than in tropical regions, because of many revitalizing mouvements (Organic, Biodynamic agriculture, EU recognition of Agroforestry etc.)
3. Mediterranean forests, woodland, and scrub	Decreasing -2	Urbaization rate very high especially in southern Mediterranean countries.
4. Tundra and high mountain habitats	Decreasing -2	Poverty lead to out migration. Indigenous people's lifestyles little supported by governments except for a few examples (Bolivia). Marginalization and poverty lead also to unsustainable practices such as overharvesting of resources for trade.
5. Tropical and subtropical savannahs and grasslands	Decreasing -2	Poverty, climate change, lack of recognition of local subsitence practices. High migration rates
6. Temperate grasslands	Decreasing -2	Same as above
7. Drylands and deserts	Decreasing -2	Same as above
8. Wetlands – peatlands, mires, bogs	Decreasing -2	Same as above
9. Urban/semi-urban	Decreasing -2	Rate of urbanization is very high and great disparity within towns especially megapoles in access to nature
10. Cultivated areas (including cropping, intensive livestock, farming, etc.)	Decreasing -2	Due to industrialization (crops and animal rearing), widespread use of GMO, development of large monocultures to feed larde demand in meat
11. Cryosphere	Decreasing -2	Major trends: people, mainly IPLCs have to face major problems including mining (e.g. Nunavut), climate change (e.g. Finland)
12. Aquaculture areas	Decreasing -2	Industrial production are increasing
13. Inland surface waters and water bodies/ freshwater	Decreasing -2	Same as above
17. Coastal areas intensively managed and multiply used by people	Decreasing -2	Due to urbanization, over fishing, lack of regulations etc.

15.5.1.2. Indicators by value

Value type	Indicator/ Proxy	Rationale/ justification for why we this indicator/ proxy was selected	Data set
Value Relational + Intrinsic	Areas including all UoA where people mainly rely on Nature for their well being	MAPs presented in Fig 8 above showing areas of co-production The data time series is long enough? Yes because all IPLCs have been living in these areas for more than 50 years. These areas include high levels of biodiversity which have a major intrinsic value because highly diverse	Map proposed as major areas of co-production of learning with nature, incorporating species richness and ethnolinguistic diversity. Others FAO figures on rural areas of small scalefarmers http://www.fao.org/fileadmin/templates/nr/sustainability_pathways/docs/Factsheet_SMALLHOLDERS.pdf Altieri and Koohafkan (2008) See also Pretty et al. 2008 Garnett et al. 2018
Value relational or	Recognition of ILPCs lifestyles in close	Available texts of conventions such as Aichi target 18:	Schmalzbauer B., Visbeck M. (Eds.) 2016. The contribution of science in implementing the

Holistic	interaction with nature and their access to their lands and resources	Target 18 highlights the following: "By 2020, and contribution of ILK to these targets 3), Other: UNDP development goals, IPBES, UNESCO recognition of Cultural Intangible Heritage, Cultural and World Heritage Cultural Landscapes, the latter defined as "Combined works of nature and humankind, they express a long and intimate relationship between peoples and their natural environment" Globally Important Agricultural Heritage Systems (GIAHS) is based on an initiative that aims at identifying, supporting and safeguarding Globally Important Agricultural Heritage Systems and their livelihoods, agricultural and associated biodiversity, landscapes, knowledge systems and cultures These different forms of recognition still need to address concretely issues of power regarding access and tenure of IPLCs in relation to their territories.	Sustainable Development Goals. German Committee Future Earth, Stuttgart/Kiel http://www.unesco.org/culture/ich/en/ethics-and-ich-00866 http://whc.unesco.org/en/culturallandscape/ https://sustainabledevelopment.un.org/partnership/?p=2309 Ding et al. 2016, Pearce F. (2016)
Value relational	Human mobility to access different natural habitats for outdoor recreation	At global levels: trends of visits for outdoor activities	Has been estimated by Wolff et al. 2017, Balmford et al 2013)
Value: Health + Economic And social cohesion	Indirect access to natural products from natural habitats (e.g. natural products consumed in towns, food, medicine materials for architecture, horticulture) typically related rich urban dwellers. Creation of new rural urban network.	Food, medicinal plants, cosmetic etc. Medicinal plants use at global level (review by Wolff et al. 2017)	review by Wolff et al. 20172017 Rover et al. 2016, Gregory et al. 2016, Dyer et al. 2015 Eloy et al. (2014) (in the Amazon)

15.5.1.3. Trends by user group

Difficult to establish robust trends by User groups because not enough data is available…

User Type	User Group	Direction of arrow	Rationale/ justification for why you think this trend is happening
Livelihood categories	Universal	Decrease	Global loss of habitats, biodiversity and access to nature due to urbanization and migrations due to poverty, climate change etc.
	Subsistence food gatherers (non-marine)	Decrease	The populations of subsistence gatherers is decreasing and or their socio-economic conditions are gradually being degraded due to diverse factors
	Subsistence food gatherers (marine)		No enough data
	Subsistence Farmers	Steady	For those who are resilient and remain as subsistence farmers, there is no reason why they would stop learning from nature
	Pastoralists (including subsistence ranchers)	Steady	Same as above
	Commercial fishers	Decreasing	Because these activities are more and more focused on artificial solutions for their problems (pesticides, artificial irrigation, use of machinery, GMOs,

	Commercial Farmers	Decreasing	Because these activities are more and more focused on artificial solutions for their problems (pesticides, artificial irrigation, use of machinery, GMOs,
	Commercial ranchers	Decreasing	because these activities are more and more focused on artificial solutions for their problems (pesticides, artificial irrigation, use of machinery, GMOs,
	Commercial foresters		
	Energy and mining	Increasing	For Energy at global possible increase in learning due to seach for novel solutions to face the petrol crisis
	Industrial	Decreasing	because these activities are more and more focused on artificial solutions
	Recreation and Tourism	Increasing	
Residence categories	Urban coastal	Decreasing	Increased urbanization of all coastal regions at global level lead to decrease in learning from natural processes
	Urban inland	Decreasing	Due to less access to green areas although some projects are being initiated to counterbalance this
	Rural coastal	Decreasing	More and more coastal regions being encroached by urbanization
	Rural inland forest	Steady	For section of the populations who stay (i.e. not considering rural exodus)
	Rural inland savannah, grassland	Steady	For section of the populations who stay (i.e. not considering rural exodus)
	Rural inland desert, tundra, barren	?	
	Nomads	Decreasing	Nomadic life is decreasing at the global level

15.5.1.4. Substitutability

Human activities that replace this NCP/

- Substitution of natural processes in agriculture with chemical products and or GMOs; monocultures instead of multi-cropping systems, agroforestry and biodiversity-rich agroecosystems.
- Industrial animal productions for food and industrial feed now known to affect human health including use of antibiotics to combat veterinary problems
- Substitution of direct contact with nature through indirect contact through nature-film and photo industry, internet and video games for children etc.
- Substitution of natural products in art, architecture: dyes, materials (metal instead of wood); artificial light instead of natural light known to affect human's psychology
- Natural medicines, replaced by chemical medicines that are not nature mimics.
- Visiting animals in zoos instead of being in contact in natural set-ups. Etc.

15.6. Integrated discussion of (co-)production and impacts on good quality of life

15.6.1. (co-) production and trends

Co-production trends of learning from nature is decreasing due to loss of biodiversity and natural habitats related to changes in land uses which mostly affects directly IPLCs who live in biodiversity rich areas. This may be compensated with learning taking place in biodiversity less rich environments such as agroecosystems still displaying a sufficiently high level of biodiversity (as opposed to industrial monocultures). Industrial plantations and animal breeding systems, to the contrary, lead people to some extent to dis-learning relationships to nature due to high external outputs replacing nature processes. Highly industrialized animal breeding systems also lead to animal ill-treatments and use of high level of antobiotics which now poses major ethical issues with major known impacts on human health. Gene editing approaches, particularly the CRISPR-Cas system, are methods used for improving crops and enabling gene manipulation towards increased resistance or productivity that depart from natural evolutionary processes. New breeds of genetically modified crops have initiated substantial debates concerning their biosafety, commercial use and regulation (Globus et al 2018)

Highly poor population sections of megapoles are associated to poor access to nature and may lead to dis-learning from nature, or stress and sometimes increase in rates of suicides (see SDG 3, Chapter 3). At the global level, resilience is developing through an increased consideration given to agroecology, vernacular architecture, and a global increase in towns of natural products, textiles etc. urban and periurban agriculture, green classes and efforts to reconnect children with nature in towns. A large set of socio-ecological movements at the local level, also show resilience towards loss of learning from nature.

Cultural expression is slowly departing from processes of learning from nature, although some artists who have left lifestyles closely connected to nature, may still include in cultural expressions, learnings from nature, especially is their expressions are recognized at the global level (http://www.ousmanesow.com/mac/index.htm; http://www.drokpa.org/tennor.html). Folk art at the global level is increasingly designed for tourists and may loose some level of identity, but global demand also represents an opportunity for developing local economies. Artistic expression in town relies very little on learning from nature except for few experiences in Land art by a few artists.

15.6.2. Similarities and differences across Units of Analysis and across User Groups

Very generally, learning from nature will greatly vary according to whether user groups live in rural areas and benefit of some level of contact with nature or whether they live in towns. Cultural contexts and activities, the latter being more or less tuned towards incorporating natural processes in economy and production systems will more or less affect their capacity to learn from nature. Direct experience from nature favors learning while indirect experience from nature may lead to dis-learning or regarding scientific innovations, relying increasingly on smaller elements of nature (molecules, genes) that are slowly being disconnected from initial natural processes where they originate. This leads in particular to use of scientific knowledge to distort natural processes such as GMO, Gene drive processes, innovations which are highly debated in relation to ethical and ecological issues raised. Scientific users should be represented in the user group table.

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15.8. Search methodology

My search was based on the following key words and approaches*: My key words:* Learning AND or Artistic AND or Biomimickry AND or Inspiration AND or Folk art AND or Gene Drive AND or Indigenous Knowledge AND or Nature films AND or African Art AND or Bioprospecting AND or Biopiracy AND or Nature symbolism AND or Art AND or Creativity AND or green spaces. I used Web of Science, Core Collections, Access through CNRS, JSTOR Access through CNRS as weall as CAIRNS.Many of my readings led me to identify some other key references in the bibliographical parts which I checked.Moreover, having co-written the NCP Food and Feed, as well as Medicinals, I could use exemples from the latter to give evidence. Some books and papers were from my own Bookshelf (e.g. Dreams of Nature), museums Catalogues (e.g. Gauguin) etc…

16. NCP 16 - Physical and psychological experiences

Lead Author: Cynthia Zayas

16.1. IPBES Definition:

Provision, by landscapes, seascapes, habitats or organisms, of opportunities for physically and psychologically beneficial activities, healing, relaxation, recreation, leisure, tourism and aesthetic enjoyment based on the close contact with nature. E.g. hiking, recreational hunting and fishing, birdwatching, snorkeling, gardening

16.2. Why is this NCP important?

16.2.1. What is the big environmental issue this pertains to?

- Many people are more remote from nature in modern society because of urbanization, loss and degradation of habitat (e.g. places where nature can be accessed), and other forces.
- Many people are now more protected from dangers of nature.

16.2.2. How does this NCP play a role?

- Nature provides the physical location and characteristics that allow physical and psychological experiences in the outdoors.
- Benefits improve both physical and mental health.
- Nature can also be scary, with material and physiological threats.

16.3. (Co-) production

16.3.1. How is this NCP produced?

To fully understand the spiritual and religious dimensions of nature in their relation to health, conceptual tools and frameworks traditionally used by the ecosystem sciences appear to be limited. More comprehensive methods are needed to fully evaluate how the spiritual benefits from nature are perceived and socially constructed in Western cultures. Here, social sciences and the humanities appear to be just as important as ecology (Milcu et al., 2013; Verschuuren, 2006), in order to analyze human attitudes and beliefs towards nature and ecosystems. Ecologists and ecological economists are increasingly considering the social sciences as a key tool to include spiritual and religious benefits of nature in their analyses (see Carpenter et al., 2009; Chan et al., 2012; Daily et al., 2009; Wallace, 2007). This alternative perspective on the relationship of human and nature does no longer consider human as engineers or consumers, but involved into complex social and cultural interactions with nature (Fischer and Eastwood, 2016). Human relation to nature has to be understood into an historical process, which is shaping our perceptions of nature and ecosystems. The integration of social sciences to the understanding of cultural ES could provide to ecology conceptual definitions of categories such as 'nature', 'culture', 'sacred', 'spiritual', 'health' or 'well-being'. Indeed, the nature-culture relationship is a cornerstone of anthropology and social sciences, even if these academic disciplines work without reference to the field of ES research (Cooper et al., 2016). Moreover, humanities can bring a critical and a historical look over these questions, which may contribute to avoid overgeneralization and romanticization (Bhattacharya et al., 2005) and help to understand the complexities of spiritual services (see for instance Stiebel et al., 2000).

Text from NCP15
Mental Health: The natural environment is generally beneficial to human well-beings in towns (Cox et al. 2017) and outdoor recreation activities are important for urban dwellers to foster well-being (Wood et al. 2013). Access to nature may be inequitable, especially in large cities.

Nature tourism: Desire for nature by urban dwellers can be achieved by travelling to nature-based touristic sites in local and distant places (Wolff et al. 2017) Urban dwellers tend to move to natural areas for leisure and develop a very high interest in nature-based tourism (Wolff et al. 2017). Balmford et al. (2015) estimates that in total, the world's protected areas are visited by 8 billion people per year, a trend that has been increasing over the past decade.

16.3.2. How is (co)production of this NCP measured?

- Measure:
  - Number of people getting out into nature, for how long
  - Specific activities people are doing (boating vs. hunting vs. hiking)
  - Brain measurements of exposure to nature
- Proxy measures:
  - Park visitation, number or area of parks/protected areas (weighted by visitation)
  - Car visits
  - Flicker photos
  - Number of indigenous people who still have jurisdiction of own land
- Model:
  - Number of people in proximity to nature with specific characteristics

16.3.2.1. Links to other NCPS

The better understanding of the spiritual and religious dimensions of nature in the Western world may also be a key instrument for promoting ecological concerns and biodiversity conservation (Posey, 1999; Sonsel, 2001). Several studies have shown that cultural ES (and especially religious and spiritual services) play a major role in helping to raise public support for protecting ecosystems, through the recognition of duties and moral responsibilities towards nature (e.g. Comberti et al., 2015; Cooper et al., 2016; Fish & Saratsi, 2015; Winthrop, 2014). The examples of health, food and well-being, in their relation to spirituality and nature clearly illustrate this phenomenon. Ecological preoccupations also arise from the current need of being 're-connected' with nature through new ways of consuming, gardening, farming, healing and relaxing. This current need for the 'natural' indicates as well that the spiritual and religious benefits can be reversed: here, the recognition of the duty of humans is towards nature (Commune 2017) (Commune:2017).

Note: Spiritual and religious benefits from nature are included both in NCP 16 (physical and psychological experiences), as nature is providing opportunities for activities such as healing, relaxation, outdoor recreation, aesthetic enjoyment, and to NCP 17 (supporting identities), as the natural world is a basis for religious, spiritual, and social-cohesion experiences. Because spirituality can be associated with inspiration and the development of skills for well-being, the NCP 15 (learning and inspiration) might be also included (Commune:2017**).**

16.3.3. Indicators of NCP (co-) production

Indicator/ Proxy
Visitation rates of parks
People in proximity to parks or natural areas
Indigenous lands
Green space in cities

16.3.4. Trends in Co-Production

16.3.4.1. General (across all units of analysis)

In the literature, it is significant to notice that most of the publications primarily associate spiritual benefits of nature with indigenous people. However, National Geographic did a whole issue on Generation X returning to national parks with many of the youth expressing that nature was the new church experience for them. The analytical lens seems to focus on indigenous people and traditional cultures in developing countries. One may be interrogative regarding to this methodological choice, which could implicitly means that traditional societies are the only societies subjected to spiritual benefits from nature. However, In the Catholic tradition this is largely represented by Saint Francis, patron Saint of Ecologists. Note also that the encyclical Laudato Si by Pope Francis (no coincidence in name selection) emphasizes our spiritual connection to nature, or to Creation. There is a significant Christian environmental movement that emphasizes our need to care for nature. Buddhism similarly has this emphasis in some sects. Very few valuable studies put the focus on the field of spiritual and religious values of nature in the Western world[3] (see Church et al., 2011; Niemelä et al., 2010; Tzoulas and James, 2010; Cooper et al., 2016) (Commune:2017**).** .

16.4. Impacts on good quality of life

16.4.1. How do we measure that value/contribution?

The numerous spas, health resorts, heavily visited national parks, beaches and retreat places accurately illustrate the need of modern societies to escape from the city and be closer to nature for few hours or few days. Cities often go to great lengths to recreate green space (Central Park, Griffith Park) or waterways (e.g. restoration of the Los Angeles River) to ensure inclusion of nature within easy access of urban citizens. Spas and wellness centers cover a wide range of structures. The analysis focuses here on spas located outside main urban areas which offer 'healing holidays' close to a retreat experience during few days to one week, rather than urban day-spas and wellness centers. These centers are located in luxurious natural

[3] 'West' and 'Western world' are used here as generic categories, associated here to modern urban ways of life and contemporary modes of social organization rather than defined geographical areas.

environments, such as seashores, rivers, mountains, forests; they advocate for a well-being experience through the immersion in nature. Benefits of nature in terms of health and well-being (understood in its physical, emotional, and spiritual dimensions) are promoted through practices such as massages therapies, complementary and alternative medicine, nature-orientated therapies, outdoor recreation, aesthetic experiences, organic food and diet recommendations. Therefore, spas and wellness centers represent a great observatory for analyzing the spiritual benefits from nature in the contemporary world (Commune:2017).

The sociological and the anthropological literature on spas and wellness centers draw attention to the genealogy of these spaces, such as the therapeutic use of thermal waters and natural sources and the birth of the hydrotherapy as a medical discipline (Weisz, 2011). This author also highlights the link between religion and the use of water as a therapeutic tool. Bastos (2011) describes these historical evolutions through the example of a spa in Portugal, from the traditional religious use of water sources to the control by the Catholic Church. In Europe, spas were historically connected to traditional healing practices and pilgrimages, before being ruled by religious principles. During the XXth century, spas were built on the standard of thermal resorts; they became highly medicalized through the introduction of hydrotherapy, and finally turned into a place for recreation, wellness and leisure during the XXIth. Weisz (2011) notes that rituality is still an important feature of the contemporary spas' experience, and that secular and scientific aspects come together with the religious and the spiritual. Spiritual and religious dimension has remained central, but is now expressed through a different medium. Discourses on the 'healing power' of nature are an important feature of the wellness industry, which emphasizes on holism, relaxation, spiritual wellbeing (Andrijašević & Bartoluci, 2004; LaFauci, 2011; Naraindas & Bastos, 2011). The work of Perriam (2015) on several retreat places in Scotland shows that spiritual and holistic connections to nature are closely associated with wellbeing and therapy. Nature is associated with therapeutic qualities, and is understood as a therapeutic agent (Speier, 2011). Practices such as yoga retreats in Europe also put the emphasis on the therapeutic and spiritual experiences arising from being in touch with nature (Lea, 2008). During the last decades, a growth of spas and health resorts has also been witnessed in Asia. In their study of the touristic use of ashrams and meditative centers in India, Sharpley et Sundaram (2005) demonstrate that the search for wellbeing, 'reconexion' and relaxation can be related to spiritual or religious practices such as pilgrimages. Investigating a brand of ayurvedic spas in India, Pordié (2011) highlights the numerous references made to the healing powers of nature, and the key role of spiritual values in the building of the spas' identity. This author also points out that spas therapists often incorporate few spiritual references to their practice such as energetical healing or prayers. Despite the lack of studies explicitly exploring the spiritual benefits of nature in the context of spas and wellness centers, the literature reviewed here clearly shows a relationship between nature-orientated experiences and relaxation, well-being and spiritual benefits. However, these benefits are difficult to quantify as they remain included in the broader category of health and well-being (Commune:2017)..

16.4.2. Substitutability

- Final
    - Tourism to places for reasons other than nature
    - Cultural and psychological benefits may not be substitutable
- Process
    - Recreation not based on nature

16.5. Summary

There are therefore 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 (Stigdotter, et. al 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 (2014 UN List). Visitation to these protected areas has also increased. In the US, 79% of the respondents in an AAA survey suggested that it was "very likely" that they would visit a national park in the following year, with millennials most likely to visit national parks. In Japan shinrin yoku or forest bathing is being promoted by the government. It is claimed to heal stress as it opens the senses and thus enable people to reconnect with the natural world (Li, 2018). The establishments of protected areas and national parks are not always beneficial for traditional peoples whose lives are intertwined with nature as in African indigenous pastoralists and hunter-gatherer communities (Laltaika and Askew, 2018). Protected areas and national parks result to impoverish condition and ultimately dispossession of peoples from their natural habitats ultimately the loss of indigenous local knowledge. Experiencing nature is beneficial to all people, but it will be a contentious issue when one's interest causes the dispossession of the other. The business of nature has recently been popularized through spas industry, mineral and natural springs, man-made garden/forests among others (https://globalwellnessinstitute.org/press-room/statistics-and-facts). This is one way of servicing the needs of the growing appetite for the experience of nature among urban dwellers in the years to come.

	Potential Nature's Contributions	**Output of the joint production**	**Impact on good quality of life**
Indicator	(a) Area of natural and trad. landscapes and seascapes (b) Number of protected areas, parks and gardens	Visitation rate to natural terrestrial, coastal and marine areas.	Increased awareness, care, mental health, cultural security, life-satisfaction
Trend During the last 50 years: 2 = Major increase (>20%) 1 = Increase (5% to 20%) 0 = No change (-5% to 5%) -1 = Decrease (-20% to -5%) -2 = Major decrease (< -20%)	(a) – 2 Decline in natural áreas (see hábitat…) (b) 2 Protected áreas have increased The 2014 UN List of protected áreas listed 209,429 protected areas covering a total area of 32,868,673 km2 - an area larger than the African continent. In total, 3.41% of the world's marine area and 14% of the world's terrestrial areas are currently protected. If Antarctica is excluded from the global statistics coverage, the percentage of the total terrestrial area protected is 15.4%. In more than 50 years, 1962-2014, there was an increased of the	2 (?) {Need visitation rates}	2 Increased awareness, care, mental health, cultural security, life-satisfaction

	number of sites from 9,214 to 209,429; representing an increased of área per square kilometer from 2,400,000 to 32,868,673. Continued rise in sites and áreas is further establsihed by the reports frommUNEP-WCMC and IUCN (2016) confirming that for the past 20 years, , there has been a dramatic increase in the number and extent of protected areas established globally, representing a growing recognition of the value of protection as a way to safeguard nature and cultural resources and mitigate human impacts on biodiversity.		
Spatial variance 3 = opposite trends in different regions 2 = same directional trends in different regions but of contrasting magnitude 1 = similar trends all over the world	2 (a) 2(b)	2 Over 30 million square kilometres have become protected in the last 50 years a nd the number of protected areas desig nated and/or recognised by countries h as doubled every decade for the last 20 years (2014 UN List).	3 Different regional patterns for Increased awareness, care, mental health, cultural security, life-satisfaction
Variance across social groups 3 = opposite trends for different groups 2 = same directional trends for different groups but contrasting magnitudes 1 = similar trends for all social groups	NA	NA	2 Experience of nature is given for most non-urban dwelling populations. Most often it is a given and taken for granted (from an expert's observations).
Degree of certainty 4 = Well established: Robust quantity and quality of evidence & High level of agreement 3 = Established but incomplete: Low quantity and quality of evidence & High level of agreement 2 = Unresolved: Robust quantity and quality of evidence & Low level of agreement 1 = Inconclusive: Low quantity and quality of evidence & Low level of agreement	4	4 Well established. From the Middle Ages, western health system connected the ideas of relations between human health processes and gardens. In this modern age, the sedentary life styles, stress from the demands of modern world resurface the ancient concept of healthy nature settings and therapies (Stigdotter, et. al 2011). There are therefore long held beliefs that human health and well-being are influenced positively by spending time in natural settings. Gardens, pastoral landscapes and natural environments with small lakes and meadows are depicted as places where people can be restored both mentally and physically. Beneficial properties are attributed to activities in nature, where one experiences natural daylight, fresh air and greenery (Ibid.).	3 The scarce literature on the topic is a limitation for a conclusive evidence.
Two to five most important papers supporting the reported trend	Ulrika K. Stigsdotter, Anna Maria Palsdottir, Ambra Burls , Alessandra Chermaz, Francesco Ferrini, and Patrik Grahn, 2011. Nature-Based Therapeutic Interventions, in K. Nilsson et al.	UNEP-WCMC and IUCN (2016). Protected Planet Report 2016. UNEP-WCMC and IUCN: Cambridge UK and Gland, Switzerland. https://wdpa.s3.amazonaws.com/Protected_Planet_Reports/244	Ellen Shepherd, E.J. Milner-Gulland, Andrew T. Knight, Matthew A. Ling, Sarah Darrah, Arnout van Soesbergen, & Neil D. Burgess. 2016. Status and Trends in Global Ecosystem Services and Natural Capital:

	(eds.), Forests, Trees and Human Health, Springer Science+Business Media B.V. 2011	5%20Global%20Protected%20Planet%202016_WEB.pdf Deguignet M., Juffe-Bignoli D., Harrison J., MacSharry B., Burgess N., Kingston N., (2014) 2014 United Nations List of Protected Areas. UNEP-WCMC: Cambridge, UK. http://wedocs.unep.org/bitstream/handle/20.500.11822/9304/-2014%20United%20Nations%20List%20of%20Protected%20Areas-20142014_UN_List_of_Protected_Areas_EN.PDF?sequence=3&isAllowed=y	Assessing Progress Toward Aichi Biodiversity Target 14. Conservation Letters, Journal for the Society of Conservation Biology. November/ December 2016, 9(6), 429–437. Wiley Periodicals, Inc. Commune, Nicolas (2017). The spiritual and religious dimensions of nature Evaluation of the literature and prospects for future research. Manuscript submitted as a contribution to the IPBES GA, 2017.05.08

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17. NCP 17 - Supporting identities

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17.1. IPBES Definition:

Landscapes, seascapes, habitats or organisms being the basis for religious, spiritual, and social-cohesion experiences

Provisioning of opportunities by nature for people to develop a sense of place, purpose, belonging, rootedness or connectedness, associated with different entities of the living world (e. g. cultural, sacred and heritage landscapes, sounds, scents and sights associated with childhood experiences, iconic animals, trees or flowers)

Basis for narratives and myths, rituals and celebrations provided by landscapes, seascapes, habitats, species or organisms

Source of satisfaction derived from knowing that a particular landscape, seascape, habitat or species exist in the present

17.2. Why is this NCP important?

17.2.1. What is the big environmental issue this pertains to?

- Global change (land use change, climate change) has or is threatening to change landscapes important to identity
- Dispossession of land,
- Cultural changes
- Erasing memories, cutting memories
- In urban areas green spaces provide common ground for social cohension

17.2.2. How does this NCP play a role?

Nature can be the basis for:

- religious and spiritual experiences
- narratives and myths, rituals and celebrations
- social-cohesion
- sense of place
- existence value

17.3. (Co-) production

17.3.1. How is this NCP produced?

Cultural identity: Local and indigenous groups have intricate relationships to nature that form identity and social cohesion (Sanga & Ortalli 2003, Ding et al. 2016). Culture important for social cohesion and cultural identity is frequently expressed in traditional or modern rituals, festivals, and food exchange networks that directly or indirectly depend upon nature. For example, many cultures incorporate the slaughter and sacrifice of animals (e.g. Madagascar). In many totemic indigenous societies, profound linkages with nature are expressed through animals as founding members and in some cases as patronyms, linking each clan to an animal (Ingold 2002). This represents not only a name but is at the origin of the social organization in its entirety (Ingold 2002). Nature affects socio-political organization (Nazarea 2016). "National identity describes that condition in which a mass of people have made the same identification with national symbols – have internalised the symbols of the nation ..." (Bloom 1990, 52). Outstanding / significant landscapes / places / objects obtain meaning that helps groups of people (nations, tribes, etc) identify themselves. "

Sense of place: Nature, including its sacred dimension, may be one reason people stay on their lands or, if choosing mobility, they maintain strong linkages with nature in their hinterlands (Ding et al. 2016; Salmon 2000, Aumeeruddy-Thomas & Lama 2008, Eloy et al. 2015). Global heritage sites are significant sources of inspiration because they integrate multi-level holistic man–nature relationships within areas that are managed by local social groups. In urban areas, green spaces, botanical gardens, and the greening of towns in general are becoming increasingly important (Wolfe and Russell 2010, Li et al. 2010, Berman et al. 2012).

Social cohesion: In urban areas for instance, green spaces and or outdoor recreational activities to visit natural sites increase social cohesion (Wood et al 2013).

"Natural or seminatural features of the environment are often associated with the identity of an individual, a community, or a society. They provide experiences shared across generations, as well as settings for communal interactions important to cultural ties. The MA acknowledges that "many societies place high value on the maintenance of either historically important landscapes ('cultural landscapes') or culturally significant species." Cultural heritage is usually defined as the legacy of biophysical features, physical artifacts, and intangible attributes of a group or society that are inherited from past generations, maintained in the present, and bestowed for the benefit of future generations (Czepczynski, 2008)" (Daniel et al, 2012). Cultural landscapes are vessels of cultural values and contribute to the identity of communities (Stephenson, 2008). Over time, altered or even heavily managed ecosystems can acquire cultural significance.

Daniel et al (2012) also make a point that a) spiritual and religious values can be instrumental in promoting biodiversity conservation (Posey, 1999; Sponsel, 2001), with some risk for underestimating the complexities of lived experiences of spirituality and religiosity; b) environmental stewardship may provide the link between religion and environmental conservation; c) attempts have been made to use sacred areas as a point of departure when creating protected areas; and d) spiritual and religious services do not generalize well across communities, and they are difficult to value in economic or monetary terms. Relations between ecosystems and religion include moral and symbolic concepts but can also center around very material concerns, such as staking claim to land contested by immigrants, invading states, or development agencies (Dzingrai, Bordillon, 1997; Spierenburg, 2004). Language is among the most powerful ways cultures map meanings through which the world is made more intelligible.

Pascua et al (2017) advise to pay attention to three more issues that are not yet commonly accepted as a CES: a) the value of security – as the feeling of safety from being in a familiar place and the feeling of knowing that you will always have some place to return; b) the perpetuation of traditional values associated with a practice; c) Cultural subsistence - a holistic approach to cultivating or harvesting subsistence resources (i.e. crops, fish, cattle) resulting in cross-cutting spiritual, physical, mental, educational, and environmental benefits.

<u>*Summary of how this NCP is produced*</u>:

- *Presence of an outstanding/distinctive/special natural feature*
- *Presence of a social/cultural group that attaches meaning to that feature*

17.3.2. How is (co)production of this NCP measured?

In the literature, efforts to evaluate spiritual and religious services from a monetary perspective appear to be absent (Daniel et al., 2012). There is yet no monetary technique for valuing these benefits (Cooper et al., 2016), although new approaches have been questioning these issues over the last decade (e.g. Bieling, 2014; Bryce et al., 2016; Daniel et al., 2012; Hernandez-Morcillo et al., 2013; Kanowski and Williams, 2009; Kenter et al., 2016). The literature on cultural ES agrees on the impossibility to quantify and to define a marketable value from these benefits (e.g., Carpenter et al. 2009, Martín-López et al. 2009; Milcu et al., 2013). Cooper et al. (2016) argued that these values cannot be captured by economical thinking, because they differ from the ES conceptual framework.

As stated before, attempts have been made to link spiritual and conservation values and places of spiritual significance have sometimes been takes as the departure points for establishing conservation areas. Daniel et al (2012) claim that "Ecologists and ecological economists are increasingly adopting methods derived from history and social sciences to include spiritual and religious services in their analyses. Examples are the Integrated History and Future of People on Earth project (Hibbard et al 2010) and the discourse based valuation methods proposed by Wilson and Howarth (2002). In contrast to the other examples of cultural ES discussed in this paper, efforts at monetary valuation of spiritual and religious services appear to be absent, even though the contribution these services could make to biodiversity protection has been recognized by scientists and policy makers". This non-measurable aspect explains why spiritual and religious services remain largely underestimated – if not invisible – from the valuation process of ES. Firstly, they are not directly related with some specific part of the ecosystem, but they result from a global relationship between humans and nature. Secondly, these services are very hard to quantify, as they provide well-being, relaxation, spiritual enlightenment, happiness: these values are non-material and they cannot be understood in monetary or financial terms. These non-material and spiritual values are part of people's cultures, and play a crucial role in shaping their perception of nature (Verschuuren, 2006)

For other issues covered by this NCP, the presence of protected areas/sites may serve as a useful proxy. However, one should remember that a) identities are cultural and b) culture also changes over time.

17.3.2.1. Links to other NCPS

Characteristics of nature supported by various other NCPs affect identity
NCP2 – pollination -

NCP3 – air quality -
NCP4 – climate -
NCP5 – ocean acidification -
NCP6 – water quantity -
NCP7 – water quality -
NCP8 – soils -
NCP9 – hazards -
NCP10 – pests –

Use of nature for these provisioning services may be intimately linked to identity
NCP11 – energy -
NCP12 – food -
NCP13 – materials –
NCP14 – medicine –

Important components of identity:
NCP15 – learning –
NCP16 – experiences -

17.3.3. Trends in Co-Production

17.3.3.1. General (across all units of analysis)

This section focuses on the field of health, relaxation and well-being, to lay emphasis on the spiritual and religious benefits from nature in Western cultures. The numerous spas, health resorts and retreat places accurately illustrate the need of modern societies to escape from the city and be closer to nature for few hours or few days. Spas and wellness centers cover a wild range of structures. The analysis focuses here on spas located outside main urban areas which offer ‘healing holidays’ close to a retreat experience during few days to one week, rather than urban day-spas and wellness centers. These centers are located in luxurious natural environments, such as seashores, rivers, mountains, forests; they advocate for a well-being experience through the immersion in nature. Benefits of nature in terms of health and well-being (understood in its physical, emotional, and spiritual dimensions) are promoted through practices such as massages therapies, complementary and alternative medicine, nature-orientated therapies, outdoor recreation, aesthetic experiences, organic food and diet recommendations. Therefore, spas and wellness centers represent a great observatory for analyzing the spiritual benefits from nature in the contemporary world. Their emphasis on ‘ecotherapy’, ‘detox’ and ‘cleaning’ practices points out a specific meaning associate to the experience of nature. This experience is also related both to consumerist and tourism, leisure and recreation, health, well-being and aesthetic aspects. The special issue of *Anthropology and Medicine* coordinated by Naraindas & Bastos (2011) illustrates the coexistence of these plural dimensions through questioning these ‘healing holidays’.

The sociological and the anthropological literature on spas and wellness centers draw attention to the genealogy of these spaces, such as the therapeutic use of thermal waters and natural sources and the birth of the hydrotherapy as a medical discipline (Weisz, 2011). This author also highlights the link between religion and the use of water as a therapeutic tool. Bastos (2011) describes these historical evolutions through the example of a spa in Portugal, from the traditional religious use of water sources to the control by the Catholic Church. In Europe, spas were historically connected to traditional healing practices and pilgrimages, before being ruled by religious principles. During the XXth century, spas were built on the standard of thermal resorts; they became highly medicalized through the introduction of hydrotherapy, and finally turned into a place for recreation, wellness and leisure during the XXIth. Weisz (2011) notes that rituality is still an important feature of the contemporary spas' experience, and that secular and scientific aspects come together with the religious and the spiritual. Spiritual and religious dimension has remained central, but is now expressed through a different medium. Discourses on the 'healing power' of nature are an important feature of the wellness industry, which emphasizes on holism, relaxation, spiritual wellbeing (Andrijašević & Bartoluci, 2004; LaFauci, 2011; Naraindas & Bastos, 2011). The work of Perriam (2015) on several retreat places in Scotland shows that spiritual and holistic connections to nature are closely associated with wellbeing and therapy. Nature is associated with therapeutic qualities, and is understood as a therapeutic agent (Speier, 2011). Practices such as yoga retreats in Europe also put the emphasis on the therapeutic and spiritual experiences arising from being in touch with nature (Lea, 2008). During the last decades, a growth of spas and health resorts has also been witnessed in Asia. In their study of the touristic use of ashrams and meditative centers in India, Sharpley et Sundaram (2005) demonstrate that the search for wellbeing, 'reconexion' and relaxation can be related to spiritual or religious practices such as pilgrimages. Investigating a brand of ayurvedic spas in India, Pordié (2011) highlights the numerous references made to the healing powers of nature, and the key role of spiritual values in the building of the spas' identity. This author also points out that spas therapists often incorporate few spiritual references to their practice such as energetical healing or prayers. Despite the lake of studies explicitly exploring the spiritual benefits of nature in the context of spas and wellness centers, the literature reviewed here clearly shows a relationship between nature-orientated experiences and relaxation, well-being and spiritual benefits. However, these benefits are difficult to quantify as they remain included in the broader category of health and well-being.

Interestingly, a large part of the literature on spas and wellness centers points out that most of the consumers do not claim for direct religious of spiritual motivations (see Perriam, 2015; Sharpley and Sundaram, 2005). Nevertheless, some of the respondents answered that they did benefit from this experience of being re-connected with nature and from the aesthetic enjoyment of the natural world. This discourse, emphasizing on the immersive aspects and the multisensory appreciation of nature, may be different from one individual to another, personal backgrounds and values. It stresses the nature of these spiritual and religious benefits, which are primarily subjective and enmeshed into health, well-being and identity dynamics. Similar issues are raised by the question of the aesthetic appreciation of nature and the benefits of such experience (Brady, 2003, 2016; Moore, 2008; Gobster et al., 2007; Parsons, 2008). A study research conducted as part of the UK National Ecosystem Assessment (Cooper, 2016) explores the nature of personal experiences of natural spaces, such as contemplating the seafront. It clearly indicates a strong continuity between aesthetic appreciations and spiritual concerns: people frequently describe "feeling part of something larger" or "living a magic moment". Similar phenomenon can be seen in the promotion of specific natural landscapes (forests, mountains, rivers) by the touristic of the wellness industry. To illustrate the possible health benefits of these landscapes, studies have used the concept of 'therapeutic landscapes' or 'medicoscapes' (see Wolf et al., 2006). This approach draw the attention to the qualities of these landscapes, such as wild open space, absence of visible human activity, the abundance of nature and rare fauna and/or flora, which are symbolically associated with health, relaxation and spiritual well-being.

From the perspective of anthropology of health, these transcendental values of nature are questioning our contemporary perceptions of purity and dirtiness. Indeed, it is possible to identify a whole range of symbolical categories used by spas, wellness centers and health resorts, which is related to the characterization of the spiritual healing benefits of nature. The common use of categories such as 'cleaning', 'draining', 'detoxifying' or 'purify body and mind' indicates that nature has an important symbolic 'cleaning' function. To fully understand this contemporary conception of nature, it is essential to notice that our modern ways of life are sometimes seen as 'not natural' and 'not healthy'. Urban ways of life, pollution and contemporary modes of food production have led to the rise of chronic and neurodegenerative diseases (see Herzlich, 1969). The fear of being 'poisoned' by the 'chemicals' from the food industry products or industrial pollutions has grown among the public, and has become a main issue for governments and non-governmental health agencies (Fischler & Pardo, 2013; Ferrières, 2002). Anthropologists have identified specific cultural conceptions underlined in these discourses: nature and natural world are viewed as fundamentally healthy, while modern societies are supposed to generate diseases because of 'poisoning' individuals (Laplantine, 1986; Pouillon, 1993). Benoist (1998) has described this phenomenon emphasizing on the 'symbolic impurity' of the modern world, which has to be understood as both physical and spiritual impurity. Contrastingly, nature (especially through its 'wild' and 'savage' aspects) is culturally associated with a religious meaning of purity. This phenomenon has been also well described by food anthropologists working on vegetarian, 'healthy' and 'organic' eaters (Adamiec, 2013; Ossipow, 1997; Lamine, 2008).

According to this framework, the role of spas and nature based therapies is to 'purge' or 'clean' these chemical impurities from the human body. Several authors such as Douglas (1966) and Zimmermann (1989) have highlighted that these categories have both a medical and a religious meaning. They should not be understood as secular categories; there is a symbolical overlap from physical pollution to spiritual impurity (see also Commune, 2015). Spas, wellness centers and nature-orientated therapies appear to be ideal places for modern individuals to be 'clean' from the impurities of modern ways of life. Spiritual and religious benefits which arose from this experience with nature and relaxation are multidimensional, as they are related to physical and emotional health, well-being and aesthetic experiences

17.4. Impacts on good quality of life

17.4.1. Different types of value

17.4.1.1. What is the NCP contribution

Spiritual and religious benefits from nature in the Western world

In the literature, it is significant to notice that most of the publications primarily associate spiritual benefits of nature with indigenous people. The analytical lens seems to focus on indigenous people and traditional cultures in developing countries. One may be interrogative regarding to this methodological choice, which could implicitly means that traditional societies are the only societies subjected to spiritual benefits from nature. Very few valuable studies put the focus on the field of spiritual and religious values of nature in the Western world[4] (see Church et al., 2011; Niemelä et al., 2010; Tzoulas and James, 2010; Cooper et al., 2016).

Rather than concluding that spiritual and religious benefits from nature do not exist in the Western world, the reasons of this lake of literature have to be discussed. Firstly, animist cultures

[4] 'West' and 'Western world' are used here as generic categories, associated here to modern urban ways of life and contemporary modes of social organization rather than defined geographical areas.

as described by anthropologists have a strong relationship with the natural world. Collective practices such as shamanism, healing, agriculture and hunting are enmeshed into knowledge systems in which nature and sacred overlap. On the contrary, Western or 'modern' societies have been characterized by sociologists as indivualistic, urban and secular societies, promoting science and technological progress rather than religious beliefs. Secondly, Western culture have idealized perspectives on indigenous people, emphasizing on their 'primitiveness' and their 'exoticism', supposedly being spiritually closer from the natural world than 'modern' individuals. Nevertheless, limiting our understanding of the spiritual benefits from nature only to indigenous people would be a great mistake, as it would implies that Western societies are not concerned by this phenomenon. This section asks what could be regarded as spiritual and religious benefits from nature in the secular cultures of the West.

Analyzing the spiritual and religious benefits from nature in Western societies also implies to re-examinate the validity of conceptual tools and definitions used, such as the 'spiritual' and the 'religious' 'benefits'. Following Chiesura and de Groot (2003), the international literature that mentions spiritual with nature tends to view the spiritual functionally, "as an important social and psychological function which is important for the cohesion of human groups". This view is rooted into the ES framework, in which an ES must demonstrate a significant relationship between ecosystem structures and functions specified in the biophysical domain and the satisfaction of human needs and wants (Daniel et al., 2012). Defining spiritual benefits of nature as an important cultural function could be an interesting approach, but these benefits remain wildly undefined and rarely quantified. An alternative approach can be found in questioning the spiritual benefits produced by nature in the Western world through the lens of health and well-being. In their literature review, Milcu et al. (2013) point out that more than half of the reviewed papers acknowledge the contribution of nature to well-being and health, particularly through mental benefits (see for instance Niemelä et al., 2011; Tzoulas and James, 2010). According to the World Health Organization (WHO, 1946), health is "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity". If spiritual and religious benefits from nature cannot be easily defined as a cultural function, it is clear that they play a key role when considering the physical, emotional, and mental aspects of health. By being related both to individual and collective identities, personal development and well-being, some spiritual benefits of nature can be analyzed through medical, psychological and social perspectives.

Especially, since the counter culture of the 70's, the idea of associating healing powers with the natural world has been steadily growing in Western cultures. In response to the high technification of modern medicine, urban ways of life and labor organization, different groups have claimed for the recognition of nature as a provider of well being, health and spiritual enhancement. Far from being anecdotic, these movements have led to the rise of alternative and complementary medicines, holistic and nature-orientated therapies, organic foods or relaxation and well-being concerns and so on. Practices such as meditation, yoga, ecotherapy and relaxation are emphasizing the importance of being 'connected' to the sacredness of nature. These therapeutic benefits of nature has also recently rose the attention of medical and psychological sciences (e.g. Berger & Tiry, 2012; Blascheke et al., 2017; Kai-Tak et al., 2016 ; Poulsen et al., 2015). 'Naturality' has also become a marketing tool for the food industry, which is promoting the 'natural' and 'healthy' aspects of its products (Lepillier, 2010). In Western cultures, the link between health, well-being and spirituality remains strong. Lexical categories such as 'relaxation', 'well-being', 'spiritual experience', 'personal development' illustrate this phenomenon. Contrasting with 'traditional' societies, spiritual experiences in the Western world appear first to be private and individual, rather than expressed during collective workshops or rituals. This is another reason for this lake of visibility: as noted Cooper et al. (2016), in secular societies, people may be reluctant in talking about spirituality in public because of fear, embarrassment or shame.

To fully understand the spiritual and religious dimensions of nature in their relation to health, conceptual tools and frameworks traditionally used by the ecosystem sciences appear to be limited. More comprehensive methods are needed to fully evaluate how the spiritual benefits from nature are perceived and socially constructed in Western cultures. Here, social sciences and the humanities appear to be just as important as ecology (Milcu et al., 2013; Verschuuren, 2006), in order to analyze human attitudes and beliefs towards nature and ecosystems. Ecologists and ecological economists are increasingly considering the social sciences as a key tool to include spiritual and religious benefits of nature in their analyses (see Carpenter et al., 2009; Chan et al., 2012; Daily et al., 2009; Wallace, 2007). This alternative perspective on the relationship of human and nature does no longer consider human as engineers or consumers, but involved into complex social and cultural interactions with nature (Fischer and Eastwood, 2016). Human relation to nature has to be understood into an historical process, which is shaping our perceptions of nature and ecosystems. The integration of social sciences to the understanding of cultural ES could provide to ecology conceptual definitions of categories such as 'nature', 'culture', 'sacred', 'spiritual', 'health' or 'well-being'. Indeed, the nature-culture relationship is a cornerstone of anthropology and social sciences, even if these academic disciplines work without reference to the field of ES research (Cooper et al., 2016). Moreover, humanities can bring a critical and a historical look over these questions, which may contribute to avoid overgeneralization and romanticization (Bhattacharya et al., 2005) and help to understand the complexities of spiritual services (see for instance Stiebel et al., 2000).

17.4.1.2. How do we measure that value/contribution?

- Direct measure:
    - Reports of wellbeing/satisfaction connected to nature impacts on spiritual, cohesion, sense of place;
    - Willingness to pay studies of existence value
- Proxy measure:
    - Number of people engaged in religions/religious activities with overt nature focus

17.4.1.3. Substitutability

- Little substitutability within tradition
    - culture says specific parts of nature are unique and critical
- Potential substitutability for final outcome
    - possible to organize around non-nature sources of meaning for spirituality, sense of place, social cohesion

17.5. Summary

Nature provides culture with the possibility to attribute value to it, and culture attributes value to nature. The abundance of natural ecosystems, especially those that have regained stability 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, 2010).In many cases identity is inseparably linked to a particular place or resource (such as indigenous peoples of the North, Pacific islands, etc). Their local economies depend strongly on the availability of local resources, but also on cultural knowledge, traditionally transmitted from generation to generation, regarding the ways of preparation, storage, and distribution of food and resources (Pascua et al 2017, Kaltenborn 1998 etc). 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., 2000) and loss of security (Pascua et al, 2017) [add reference to America's regional assessment]

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 (Daniel et al, 2012), 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. Similarly, nature has become engrained in the cultural identity of some countries such as Bhutan, and Costa Rica where NCP have been integrated into livelihoods and national economies.

	Potential Nature's Contributions	**Output of the joint production**	**Impact on good quality of life**
Indicator	Abundance of slowly changing ecosystems (time past last land use change	Identity value Happyness?	Increased awareness, care, mental health, cultural security, life-satisfaction
Trend During the last 50 years: 2 = Major increase (>20%) 1 = Increase (5% to 20%) 0 = No change (-5% to 5%) -1 = Decrease (-20% to -5%) -2 = Major decrease (< -20%)	**-2** The abundance of natural ecosystems, especially those that have regained stability over longer periods of time, could be seen as a prerequisite for supporting identities. However, without culture this remains a potential only.	**a) -2** **b) 2** Decrease in local resource-based economies a) Different cultural processes that lead to loss of traditional knowledge and lifestyle and thereby traditional identities b) Increase in consciousness and awareness, in valuing nature and it contributions in urban/western cultures	**a) -1** **b) 1** a) 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, loss of sense of security. b) High identity value results in better social cohesion, stronger sense of place, spiritual and cultural well-being and thereby better care for the environment.
Spatial variance 3 = opposite trends in different regions 2 = same directional trends in different regions	**1** Proven by other ncps	1 Similar trends as described in previous	3 Decreasing values in areas where place-based cultures prevail

but of contrasting magnitude 1 = similar trends all over the world			Increase in consciousness and awareness, in valuing nature and it contributions in different cultures, especially in western/urban cultures
Variance across social groups 3 = opposite trends for different groups 2 = same directional trends for different groups but contrasting magnitudes 1 = similar trends for all social groups	NA	NA	3 Different cultural processes that lead to loss of traditional knowledge and lifestyle and thereby traditional identities (ILK) Increase in consciousness and awareness, in valuing nature and it contributions in different cultures
Degree of certainty 4 = **Well established**: Robust quantity and quality of evidence & High level of agreement 3 = **Established but incomplete**: Low quantity and quality of evidence & High level of agreement 2 = **Unresolved**: Robust quantity and quality of evidence & Low level of agreement 1 = **Inconclusive**: Low quantity and quality of evidence & Low level of agreement	4	1 General difficulties reported in assessing cultural NCPs.	2
Two to five most important papers supporting the reported trend		Verschuuren, Bas, et al., eds. 2010. Sacred natural sites: conserving nature and culture. London, Washington D. C.: Earthscan Daniel TC, Muhar A, Arnberger A, Aznar O, Boyd JW, Chan KMA, Costanza R, Elmqvist T, Flint CG, Gobster PH, Gret-Regamey A, Lave R, Muhar S, Penker M, Ribe RG, Schauppenlehner T, Sikor T, Soloviy I, Spierenburg M, Taczanowska K, Tam J, Dunk A von der (2012) Contributions of cultural services to the ecosystem services agenda. Proceedings of the National Academy of Sciences of the United States of America, 109(23):8812–8819	Milcu AI, Hanspach J, Abson D, Fischer J (2013) Cultural Ecosystem Services: A Literature Review and Prospects for Future Research. Ecol. Soc., 18(3**)**

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18. NCP 18: Maintenance of options for the Future

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18.1. IPBES Definition:

Maintenance of options: Capacity of ecosystems, habitats, species or genotypes to keep human options open to support a later good quality of life.

18.2. Why is this NCP important?

Biodiversity is the foundation for a wide variety of contributions to people, including future contributions that are currently unanticipated (i.e. **options**), and safeguarding current contributions under unanticipated future conditions (i.e. **insurance**). That is, nature makes a contribution to people by providing insurance that society can continue to have the option of having various benefits/services, even in the face of unanticipated global change. Both of these aspects keep human options open in order to support a later good quality of life.

Options, in their broadest sense, are associated with the fact that new benefits can be discovered in the future. Thus, biodiversity in the present provides a benefit as a reservoir of yet-to-be discovered uses from known and still unknown species and biological processes. Biodiversity is also a constant source, through evolutionary processes, of novel biological solutions to the challenges of a changing environment (Díaz et al., 2015). In other words, the options provided by biodiversity stem from the benefits living variation can provide to possible new future uses and benefits. Examples of benefits that could stem from these options include the future discovery of new drugs, including using natural products as "leads" to synthesize new drugs de novo (Newman and Cragg, 2012), or the inspiration for technological innovation offered by the huge variation of traits and adaptations that organisms have evolved (e.g., bio-mimicry, which is nature-inspired innovation).

Insurance is here considered to relate to the importance of ecosystem resilience. It refers to the ability of ecosystems to maintain their integrity as functioning systems and their capacity to deliver ecosystem services and other benefits to people. In the present context of global change, things that are not beneficial now may become highly beneficial in the future. The contribution of ecosystems to climate change regulation, especially to its mitigation, is becoming more important. Benefits associated with this resilience are then not linked to the particular state of nature, the flow of benefits, or the quality of life, but rather to their ability to cope with change in ways that maintain the ecosystem over time (Pascual et al., 2010) (for more details see NCP15 Learning).

The insurance component of NCP18 can work in several ways. First, biodiversity at all levels allows communities and ecosystems to respond adaptively through resistance/resilience/redundancy to environmental change, including climate change. Second, diversity within species enhances the potential for natural populations to adapt genetically and/or acclimate to various aspects of environmental change, thus increasing the resilience of populations. This ongoing evolution of biodiversity, often called “rapid” or “contemporary” evolution, can also occur for specific traits that have ecological effects (Des Roches et al., 2018). As a result, diversity with species generates “eco-evolutionary dynamics” through its influence on both the population dynamics of those species and also the key ecological traits of those species (Hendry, 2017).

NCP18 ensures the continued future maintenance of many other NCPs, with examples including erosion prevention, carbon storage, and water purification; and it helps to prevent a reduction in human options to support good quality of life. For instance, when one species is lost from a system, for other species to step in a continue to serve the original function – such as production of biomass. Such roles of NCP18 will be especially vital in cases where the direction and magnitude of environmental change is unknown. Further, NCP18 provides insurance for the maintenance of options to benefit from NCPs that are currently unanticipated. In summary, NCP18 refers to biodiversity (living variation at the level of genes, species and ecosystems) providing both insurance that current NCPs also can be delivered under strongly changing environmental conditions, and it provides options for currently unanticipated uses and contributions to people.

18.3. (Co-) production

18.3.1. How is this NCP produced?

NCP18 is mainly produced by variation in life forms interacting with the environment around them. This NCP is thus underpinned by the wealth of morphological, physiological, and behavioral traits that organisms have achieved through evolution and development. All of this variation is the product of past evolution on various time scales ranging from millions of years to just last year, in each case interacting with current environments through organismal development and behavioral choices (e.g., trait plasticity). This same variation, and that which evolves into the future, will later interact with new environments.

NCPs are jointly shaped by nature and people. As the earlier sections of this chapter on Drivers (section 1) and Nature (section 2) make clear, the actions of people affect nature in numerous and profound ways. In turn, changes in biodiversity and the structure and functioning of ecosystems also have a profound impact on what whether people enjoy a good quality of life.” As a specific co-production example,(Bellon et al., 2015) describes how on-farm conservation produces diversity that maintains options. Thus, human-influenced contemporary evolution can produce NCP18

The diversity of traits that determine options and insurance are produced at several different levels. **Species diversity** (e.g., numbers of species) can generate resilience at the community and ecosystem levels by providing the capacity to persist and contribute to quality of life in the face of strong environmental change – as seen in various biodiversity-ecosystem function experiments. **Phylogenetic diversity** (accounting not just for species numbers but also for evolutionary relationships among species) is typically even more predictive than is species diversity of the function of a current community, insurance of those functions, and options for the future. **Intraspecific diversity** (phenotypic and genetic variation within species, both among and within populations) is similarly important to current functions and services of communities (Des Roches et al., 2018), as well as options and insurance for the future. For instance, **genetic variation** within species forms the basis for evolutionary resilience to environmental change, as well as for the future generation of more options – traits that do not yet exist and yet will be useful for good quality of life. **Ecosystem diversity** then incorporates all of these aspects by considering how all of these elements are assembled into an ecosystem and how those ecosystems vary across time and space. All of these levels of diversity apply not only in natural habitats but also in anthropogenic landscapes including agroecosystems

Several evolutionary mechanisms generate and maintain diversity at these various levels are several (reviewed in Hendry et al., 2011). First, mutation is the ultimate source of all genetic variation. Second, recombination and other ways of shuffling DNA variation within genomes can generate new genetic (and phenotypic) traits. Third, natural (and sexual) selection influence the spread of various alleles and allele combinations. Fourth, gene flow and hybridization move alleles from one gene pool into other gene pools. Some factors specifically maintaining variation within populations include heterozygote advantage, spatial and temporal variation in selection, high mutation rates, gene flow with other populations of the same species, hybridization with other species, and negative frequency dependence (where rare genotypes have an advantage over common genotypes). Some factors maintaining diversity in a community of species include niche partitioning, facilitation, mutalism, movement among locations, and con- versus hetero-specific density dependence.

Summarizing, both options and insurance depend on both higher level (phylogenetic and species diversity) and lower level (intraspecific) biodiversity, as well as their interaction with geological and climatological process, and – of course – human social-ecological resilience. All levels of diversity reflect past evolution and provide the basis for ongoing and future evolution. All levels of diversity are critical for maintaining the insurance and option functions of NCP18.

18.3.1.1. Links to other NCPS

Any NCP that depends on organisms will be directly influenced by NCP18. Thus, any situation where different organisms make different contributions to an NCP that NCP will be influence by NCP18. As these influences are well known and examples abound, we do not list them in detail. However, we do here highlight a perhaps less appreciated way in which NCP18 might influence other NCPs. Specifically, changes in the phenotypes of organisms on short time scales will influence many NCPs in the futre. The table below outlines specific roles for contemporary evolution (or other forms of rapid trait change) in the other 17 NCPs, along with specific corresponding examples.

Effects of rapid evolution on Nature's Contributions to People

NCP	Role(s) of Evolution	Specific example
1. Habitat creation and maintenance (Nature group)	1. Genetic variation (and its evolution) in important (keystone, foundation) plant species influences many community and ecosystem properties. 2. Evolution of (or	1. Studies of *Populus* by many authors (e.g., Bailey et al. 2009). 2. Beavers show differential removal of *Populus* trees with different tannin genotypes,

	caused by) "ecosystem engineers" can change how they shape the environment.	which has many cascading influences on riparian ecosystems (Bailey et al., 2004).
2. Pollination and propagule dispersal	1. Rapid evolution of plant reproductive systems in response to pollinator decline improves plant fitness. 2. Rapid evolution of dispersal traits in response to habitat fragmentation.	1. Experimental study with *Mimulus guttatus* (Bodbyl Roels and Kelly, 2011). 2. Urbanization leads to the evolution of reduced dispersal in *Crepis sancta* (Cheptou et al., 2008).
4. Regulation of climate	1. Rapid evolution of marine phytoplankton increases carbon uptake. 2. Plants and soil microorganism influence rates of weathering that in turn controls CO2 sequestration.	1. Analysis and projection by (Collins, 2011) 2. Analysis of CO_2 sequestration and lifetime of fuel CO_2 (Archer et al., 2009).
5. Regulation of ocean acidification	1. Rapid evolution of marine phytoplankton increases carbon uptake. 2. Rapid evolution of many species facilitates persistence in the face of increasing acidification.	1. Analysis and projection by (Collins, 2011). 2. Reviewed in (Sunday et al., 2014)
7. Regulation of freshwater and coastal water quality	1. Rapid evolution of fish influences water clarity. 2. Zooplankton evolve increased ability to consume toxic cyanobacteria.	1. Mesocosm studies on stickleback fish (Harmon et al., 2009). 2. Studies of *Daphnia* "resurrected" from sediments in Lake Constance (Hairston et al., 1999)
8. Formation, protection and decontamination of soils and sediments	1. Genetic variation in plant species influences decomposition rates and nutrient cycling in soils. 2. Soil communities "evolve" to local plant genotypes, which has positive feedbacks on plant growth. 3. Metallophyte plants have adapted to highly toxic soils.	1. Studies of tannins in *Populus* trees (e.g., Bailey et al. 2009). 2. Studies of *Populus* trees by Schweitzer (Pregitzer et al., 2010)Evol Ecol). 3. Review in (Bothe and Słomka, 2017)
9. Regulation of the impacts of hazards and extreme events	1. Genetic variation within species enhances ecosystem recovery after extreme temperatures. 2. Genetic variation within species makes them more resistant to biological invasions.	1. Seagress (*Zostera marina*) during a European heat wave (Reusch et al., 2005). 2. Many studies, with an example being *Solidago* by (Crutsinger et al., 2008).
10. Pest, disease and stress regulation	1. Rapid evolution of resistance to herbicides, with reductions of productivity. 2. Rapid evolution of resistance to diseases.	1&2. From (Hendry et al., 2011): "Heap (1997) reports '183 herbicide-resistant weed biotypes (124 different species) in 42 countries'. (Whalon et al., 2008) list 7747 cases of resistance evolution to 331 compounds in 553 pest arthropod species. For instance, brown rats (*Rattus norvegicus*) have evolved

		resistance to warfarin at least partly through pre-existing variants of the gene VKORC1 (Pelz et al., 2005), and the same is true for blowflies (*Lucilia cuprina*) evolving resistance to malathion (Hartley et al., 2006)."
11. Energy	1. Rapid evolution (human directed) can improve biofuel production	1. Xylose fermentation by yeast based on genetic engineering(Lee et al., 2014)
12. Food and feed	1. Rapid evolution of harvested fish populations influences their productivity, resilience to exploitation, and recovery following collapse. 2. Use of refuge strategies to prevent (or at least slow) the evolution of resistance to pesticides. 3. Genetic variation in crops reduces susceptibility to disease.	1. Many examples, with a recent modelling example being (Dunlop et al., 2015). 2. Evolutionarily informed refuge strategies appear to be effective in reducing the evolution of resistance to bt crops (Carrière et al., 2010). 3. A well known example is for rice in China dealing with rust diseases (Zhu et al., 2000).
13. Materials	1. Multiple use of biomaterials in medicine and industry	1. summary of multiple uses and potential of biomaterials (NAS Report 2003 on materials research to meet 21st century defense needs).
14. Medicinal, biochemical and genetic resources	1. Strategies are designed by managers to reduce the evolution of resistance in bacteria, viruses, cancer, etc. 2. Strategies are designed by managers to retain genetic variation in species facing declines.	1&2. How drug sanctuaries can be used to prevent the spread of antibiotic resistant bacteria (Hutchison et al., 2010), (Leale and Kassen, 2017)
15. Learning, artistic, scientific and technological inspiration	1. Rapid evolution of iconic study systems – most obviously Darwin's finches in Galapagos. 2. Selfish gene evolution inspires gene editing tools for biological control 3. Art inspired by evolution	1. Work by Peter and Rosemary Grant (and others) covered by countless media and appearing in all biology textbooks. 2. Site-specific selfish genes as tools for the control and genetic engineering of natural populations (Burt, 2003). 3. citations within journal *Leonardo*
16. Physical and experiential interactions with nature	1. Trophy hunting causes evolution of reduced trophy size or frequency. 2. Recreational fishing leads to the evolution of decreased catchability.	1. Trophy hunting of bighorn sheep leads to smaller horns (Pigeon et al. 2016). 2. Experimental studies with large mouth bass.(Philipp et al., 2009).
17. Symbolic meaning, involving spiritual, religious, identity connections, social	1. Evolution can influence the multiple organismal traits valued by indigenous communities.	1. Evolution of reduced body size in harvested salmon (many studies, e.g., (Lewis et al., 2015) reduces their value to north-temperate indigenous communities.

cohesion and cultural continuity		

18.3.2. Indicators of NCP

NCP18 is based on biological variation of various types and levels of biological organization. Many indices/indicators have been developed for quantifying this variation – and extensive databases exist for some of them. The table below organizes some of these indices into a first level as "within species" (Table 7) and "among species" (Table 8). The different indices have different strengths and weaknesses and are most useful under different conditions and for different types of inferences. Note also that any measure of "biodiversity" (e.g., PD) has a vast number of metrics associated with it - we can calculate complementarity, expected loss, pairwise differences, homogeneity, endemism, and many other measures (see Faith 2017 for review) – so we do not list all of them here.

Importantly, a number of these indices/indicators can be calculated at the global scale. One example is total PD calculated globally or for regions, using one or more indicator taxonomic groups (see Table 10 below). Another example is the fractional loss of range extent or environmental space for a species (Mimura et al. 2017) or changes in the number of individuals and populations within species (Ceballos et al., 2017) – as all of these demographic metrics correlate with genetic diversity.

Table 7. Some common indices of within-species diversity*, categorized into "trait based" (phenotypic traits often linked to the evolutionary fitness of organisms), "molecular marker-based" (genetic variation potentially – but not necessarily – linked to evolutionary fitness), "phylogeny based" (evolutionary relationships among genetic variants or populations), and "demography based" (population parameters linked to the number of organisms and their distribution through space and time).*

WITHIN SPECIES	Within population	Between population	DATABASES	COMMENTS
A) Trait based				
Quantitative genetic variation	- Heritability (h^2)	- Qst (traits)	H2DB: heritability database (http://tga.nig.ac.jp/h2db/)	(Kaminuma et al., 2013)
Phenotypic variation	- phenotypic variance (Vp) - additive genetic variance (Va)	- Pst	PhenomicDB: multi-species genotype/phenotype database (https://omictools.com/phenomicdb-tool)	(Kahraman et al., 2005)
B) Molecular marker based				
Neutral variation (markers not linked to traits under selection)	- heterozygosity (He) - effective number of alleles (A_e) - haplotype (h) and nucleotide (π) diversity	- F_{ST} (based on allele frequencies) - R_{ST} (for microsatellites; assumes	Data on molecular loci (e.g. microsatellites, DNA sequences, RNA, transcriptomes, SNPs) for multiple taxa:	*Nucleic Acids Research*, 2017. 45, issue D1

		stepwise mutation model) - *D* (Nei's genetic distance) - $N_e m$ (gene flow) - Dxy (divergence) - Molecular assignment of individuals to populations	GenBank (https://www.ncbi.nlm.nih.gov/genbank)	
Non-neutral variation (markers linked to traits under selection)	- heterozygosity (He) - haplotype (h) and nucleotide (π) diversity	- F_{ST} - *D* - $N_e m$ - Dxy - Molecular assignment of individuals to populations	Data on non-neutral loci (e.g. RNA, TLS-targeted locus study; SNPs) for multiple taxa: GenBank (https://www.ncbi.nlm.nih.gov/genbank) Human variation databases: Locus reference genomics (LRGs) (http://www.lrg-sequence.org); RefSeqGenes (http://www.ncbi.nlm.nih.gov/projects/RefSeq/RSG/)	(Küntzer et al., 2010)
C) Phylogeny based				
Phylogenetic variation (of genes or populations within species)		- phylogenetic relationships (e.g. Bayesian, Maximum-likelihood trees) - haplotype networks - summary statistics (Tajima's *D*, Fu's *Fs*)	Genetic, taxonomic and geographic information of species: GenBank (https://www.ncbi.nlm.nih.gov/genbank) Species georeferenced distribution data: GBIF (https://www.gbif.org/)	Towards automated phylogeography: (Gratton et al., 2017).
D) Demography based				
Demographic variation	- abundance - population size	- range size, species distribution modeling - skyline plots - hierarchical Approximate Bayesian Computation test (hABC)	COMADRE Animal Matrix Database and COMPADRE Plant Matrix Database (http://www.compadre-db.org/)	(Salguero-Gómez et al., 2016)

Table 8. Some common indices of among-species diversity *(within or among communities of organisms) categorized along similar lines to those explained in the caption to Table 7. Differences include a general absence of "marker based" indices here and the addition of "complexity based" indices.*

AMONG SPECIES	Within communities	Among communities	DATABASES	
A) Trait based	- functional diversity (FD), rarity, redundancy, vulnerability - community-weighted mean trait value (CWM)	- community weighted mean of traits - trait convergence assembly pattern (TCAP) - trait divergence assembly pattern (TDAP) - functional betadiversity	See databases under non-genetic mechanisms, section B Botanical Information and Ecology Network (BIEN database) TRY, eFlower (http://eflower.myspecies.info/proteus)	(Enquist et al., 2016) (Maitner et al., 2017) (Violle et al., 2017) (Frainer et al., 2017) (Mouillot et al., 2014) (Jetz et al., 2016)
B) Phylogeny based	- phylogenetic diversity (PD) - overdisperion/ underdispersion taxonomic diversity and distinctness - phylogenetic species richness (PSR), clustering (PSC), evenness (PSE), variability (PSV)	- phylobeta diversity - Phylogenetic structure of a community - Phylogenetic betadiversity	Phylogenetic Diversity of Vertebrate species by Terrestrial Ecoregion (Data Basin Dataset) (http://app.databasin.org/app/pages/datasetPage.jsp?id=4c0ab10592b14a7fb29588eda42a0d42 Data Dryad (datadryad.org) TreeBASE (https://treebase.org/treebase-web/home.html) Open Tree of Life (https://tree.opentreeoflife.org/)	(Hoekstra et al., 2010) (Helmus et al., 2007)
C) Demography based	- number of species - equitability (commonness and rareness) - species abundance distribution - mean species abundance (MSA) - endemism (% endemics in community)	- betadiversity (species turnover) - gamma diversity (total diversity of species in a landscape) - nestedness	PREDICTS data base (www.predicts.org.uk) Map of Life (http://mol.org)	(Hutchison et al., 2010) (Hudson et al., 2014)
D) Complexity based	- emergence (Shannon's Information) - self-organization - complexity - homeostasis - hamming distance) - dissimilarity - cohesion - connectance (numbers of links		Long-term monitoring of community assemblage North Temperate Lakes: https://lter.limnology.wisc.edu/ CTFS-ForestGEO: http://www.forestgeo.si.edu/ Long term Ecological Research Network https://lternet.edu/	(Herren and McMahon, 2017) (Fernández and Gershenson, 2014) (Gershenson, 2014) (Schieber et al., 2017) Herren and MacMahon 2017

	by the number of nodes)			

18.3.3. Trends in Co-Production

18.3.3.1. General (across all units of analysis)

Indicators of NCP18 can be measured at any geographic or taxonomic scale, and some have been used to infer trends in NCP18 through time.

Intraspecific diversity

Many assessments have been made of the extent of within-population and among-population diversity at different levels (i.e., as number of populations, number of species, or as phenotypic and genetic diversity. The overall trend from these studies is that diversity is declining in most species in most places. Here we provide some specific examples.

1. One proxy for diversity within a species is simply the number of populations in that species – because much of the diversity within species is distributed among populations. Ceballos et al. (2017) found that "the rate of population loss in terrestrial vertebrates is extremely high—even in 'species of low concern.' In our sample, comprising nearly half of known vertebrate species, 32% (8,851/27,600) are decreasing; that is, they have decreased in population size and range. In the 177 mammals for which we have detailed data, all have lost 30% or more of their geographic ranges and more than 40% of the species have experienced severe population declines (>80% range shrinkage)." Invertebrates, including pollinators, are equally as threatened as vertebrates species (Dirzo et al., 2014).

2. The size of a population also can be a good representation of the genetic diversity it may hold. Smaller populations typically have less genetic diversity and will loose it at a higher rate relative to large populations (see Table 7). In general, many populations are becoming smaller due to habitat loss and also fragmentation (Young et al., 1996; Bender et al., 1998), which divides large populations into small units. The effects of these changes are exemplified by the Brazilian forest toad species *Rhinella ornata*. The forest habitat of this species has been fragmented by agricultural fields. Despite the toads being able to cross such fields, smaller forest fragments in Brazil have less genetically diverse populations than large fragments because they can sustain fewer individuals (Dixo and Martins, 2008).

3. Trends in diversity for crops and agricultural species are well known and also show a frequent decline. Specifically, among crops, "about 75 percent of genetic diversity was lost in the last century as farmers worldwide switched to genetically uniform, high-yielding varieties and abandoned multiple local varieties" (IPBES report). Wild relatives of crops, typically the species from which the crops were derived, are declining at alarming rates. These ancestral species are projected to lose up to 60% of their range by 2070, which, without mitigation, could decrease their genetic diversity because

population sizes will be reduced(Aguirre-Gutiérrez et al., 2017). This decline could ultimately reduce the diversity that could have assisted future crop improvement.

4. Miraldo et al. (2016) "georeferenced 92,801 mitochondrial sequences for >4500 species of terrestrial mammals and amphibians; and found that "genetic diversity is 27% higher in the tropics than in nontropical regions. Overall, habitats that are more affected by humans hold less genetic diversity than wilder regions …" However, inferences of diversity declines were indirect (diversity was lower in areas affected by humans), rather than the direct tracking of diversity change through time.

5. Studies that have directly examined genetic diversity in the same populations over time, either by using either decades-old museum collections (e.g., the grasshopper *Oedaleus decorus*; Schmid et al., 2017), or centuries-old ancient DNA from archaeological excavations (e.g., Ramakrishnan and Hadly, 2009), have also shown a decrease in diversity. For instance, the modern Swiss populations of the grasshopper *O. decorus* were found to have lost considerable genetic diversity across the genome relative to museum specimens collected from the early 19^{th} century. This loss was argued to be due to changes in farming practices and several local extinctions (Schmid et al., 2017). Comparisons of musk ox (*Ovibos moschatus*) from 45,000 to 700 years before present also showed loss of diversity in the modern populations, presumably due to habitat loss (MacPhee et al., 2005). Trends in medicinal plants also show, for some endangered species, that intraspecific diversity is endangered due to harvesting pressure in habitats where some species are most vulnerable as opposed to populations with a lower vulnerability in more favourable habitats (Ghimire et al. 2008).

6. DiBattista (2008) performed a quantitative review that analyzed measures of genetic diversity within populations for studies that had comparable data for undisturbed populations and populations disturbed by various human influences. The author found (Figure 9) that "human disturbances are associated with weak, but consistent changes in neutral genetic variation within natural populations. The direction of change was dependent on the type of human disturbance experienced, with some forms of anthropogenic challenges consistently decreasing genetic variation from background patterns (e.g., habitat fragmentation), whereas others had no effect (e.g., hunting/ harvest) or even slightly increased genetic variation (e.g., pollution)."

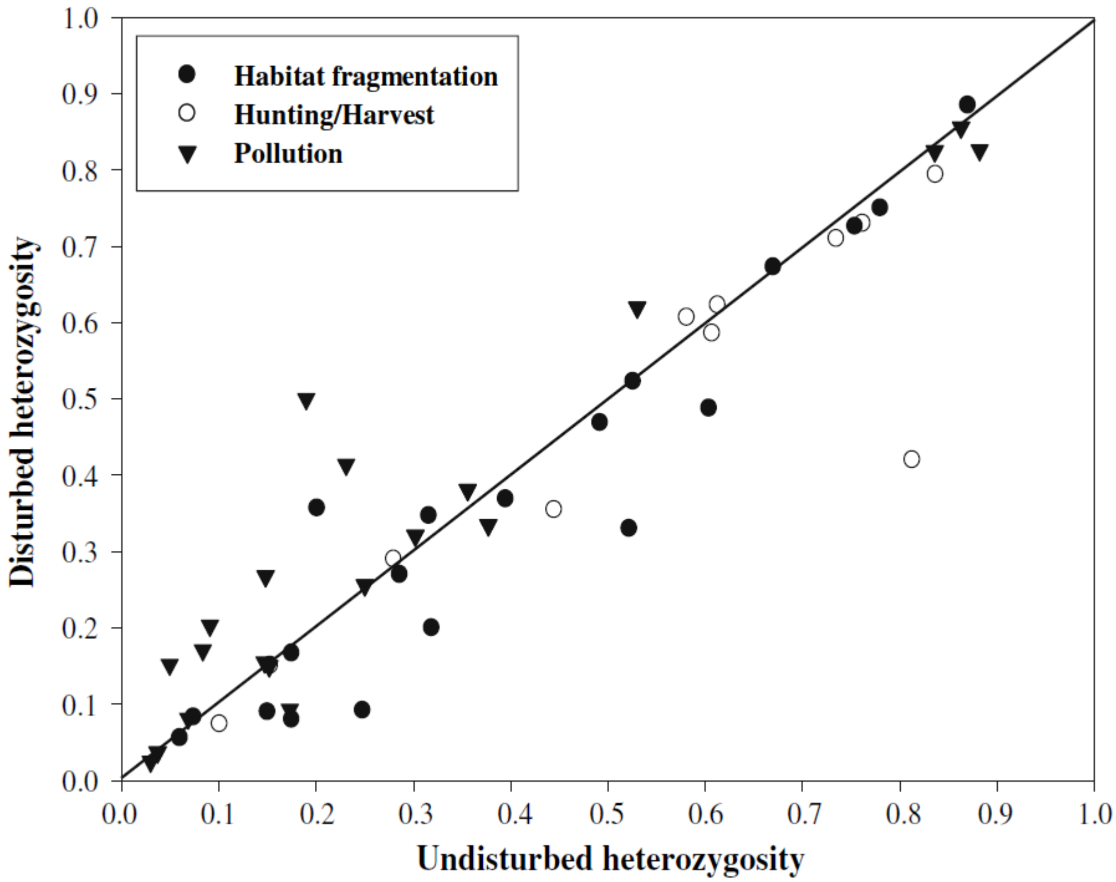

Figure 9 (from DiBattista 2008). "The relationship between disturbed and undisturbed heterozygosity estimates reported within the same study (Pearson Product Moment Correlation: r = 0.93, P < 0.0001), considering all categories of disturbance (N = 50). The line in bold represents a line of unity, which is the point at which heterozygosity estimates in disturbed and undisturbed populations are equal. Data points below the line of unity indicate a negative impact of disturbance, whereas points falling above the line are positively impacted by human disturbance" (DiBattista 2008).

Table 9 summarizes ways in which intraspecific diversity can change through time, and the key drivers of such trends. Genetic diversity provides the building blocks for one of the three mechanisms described (adaptation, dispersal, or plasticity) by which species can respond to future threats, such as climate change (Hoffmann and Sgró, 2011). Consequently, the overwhelming trend for diversity declines forebodes extensive repercussions on biodiversity in coming generations.

Table 9. Drivers of changes in intraspecific diversity over time *can be identified through examining the number of populations of a species, the size of the populations and the genetic diversity within populations and species. Recent examples overwhelmingly suggest a global decline in diversity.*

Trends of intraspecific diversity over time	**Drivers of such change**	**Examples**
Stable	1. In a population of constant size, the input of new diversity by mutation and the loss of diversity can balance, so that the level of diversity will remain constant over generations (Crow and Kimura, 1970).	1. Over 30 years, genetic diversity remained stable in a population of lake brown trout (Charlier et al., 2012). Furthermore, ancient DNA showed stable diversity over time periods ranging from 100 to 3000 years (reviewed in: (Ramakrishnan and Hadly, (2009))
Decrease	1. *Declining population sizes* can lead to loss of genetic variation due to an increase in genetic drift (Biebach et al., 2016). 2. An increase in *habitat fragmentation* is leading to smaller and less connected populations. This drives diversity loss through increased genetic drift (e.g. (Dixo and Martins, 2008) Harris et al., 2016). 3. *Extinctions* are becoming more common across all levels of biodiversity, including populations within species (Dirzo et al., 2014; Ceballos et al., 2017). This is an extreme form of genetic diversity loss.	**1.** Smaller islands in the Galapagos have smaller populations of Galapagos Mocking birds, which show a greater random change in diversity over 100 years and lower diversity than large populations due to stronger genetic drift (Hoekstra et al., 2010) (Hoeck et al., 2010); (Keller et al., 2012) **2.** Diversity loss in small fragmented populations is seen in cities (e.g. butterfly species, (Rochat et al., 2017), in rural areas separated by roads or railway tracks (Przewalski's Gazelle, (Yu et al., 2017) and in species isolated in nature reserves (Grauer's Gorilla, (Baas et al., 2018). 3. Ceballos et al. (2017) find that, for mammals, "32% (8,851/27,600) are decreasing; that is, they have decreased in population size and range"
Increase	1. *Exposure to pollutants* and other mutagens can increase rates (Johnson and Munshi-South, 2017). These mutations can be good or bad, but will likely occur too infrequently to balance out loss of variation from other sources 2. *Hybridisation* is a natural process that has increased in frequency both because human activities often move organisms across natural geographic barriers and because climate change is shifting species distributions (Scheffers et al., 2016). Hybridisation can increase diversity within a species by transferring variation among species, or genetically divergent populations, to another (introgression) (Runemark et al., 2018). It is important to highlight that hybridisation can also have the opposite effect –decreasing diversity–, when the	1. Herring gulls display a higher mutation rate in industrial cities relative to rural or nonindustrial areas (Johnson (Johnson and Munshi-South, 2017). 2. Hybridisation between the domestic goat and the Alpine ibex in Switzerland, lead to an increase in immune gene diversity in the Alpine ibex (Grossen et al., 2014). 3. Migration of Cory's shearwater has maintained diversity across isolated and small populations, keeping

	hybrids drive one (or both) parental species to extinction(Milián-García et al., 2015.) 3. *Movement of individuals* within their natural range by humans or migration can increase diversity by combining smaller population units into one large metapopulation and by reducing genetic drift (Crow and Kimura, 1970). It should be noted that movements are greatly reduced in areas with high frequencies of human activities, which may reduce the frequency this occurs (Tucker et al., 2018)	diversity levels stable since the Holocene (Ramírez et al., 2013)

Phylogenetic diversity (PD)

The status and trends of phylogenetic diversity can be assessed by linking phylogenies to the IUCN red list status of species. Such assessment of imperiled PD is well-established in the global EDGE of Existence program (www.edgeofexistence.org/). In EDGE, "Evolutionary Distinctiveness" measures the proportion of PD (measured as branch lengths in millions of years) by giving the species credit for a branch inverse-weighted by the number of species sharing that branch. Available information includes tabulated published lists of Evolutionary Distinctiveness values associated with phylogenetic trees, and IUCN red list assessments of the corresponding species. The sum of the tabulated Evolutionary Distinctiveness values of the threatened species within a given taxonomic group approximates its total threatened or "imperiled" PD (an estimate of the expected loss of PD and corresponding loss of maintenance of options). Many related regional and global studies (Safi et al., 2013); (Tonini et al., 2016); (Yessoufou et al., 2017) (Daru et al., 2013); Forest et al, in review) also provide data suitable for assessment. Table 10 shows these assessments for multiple taxonomic groups from the Europe and Central Asia regional assessment. Tables exist for all 4 regions and globally.

Table 10. Imperiled phylogenetic diversity (PD), for six major taxonomic groups. *The units of PD (Faith 1992) are millions of years. Taxonomic groups are ordered from left to right by the magnitude of their total imperiled PD as a fraction of the total phylogenetic diversity of the group. The estimate of the fraction of Imperiled PD represented by species in Europe and Central Asia is approximated by the fraction of all threatened species found in the region (4.6%). Global "non-imperiled" phylogenetic diversity includes portions assessed as non-threatened and also portions that cannot be identified as imperiled because the associated species are Data Deficient (DD). Data sources: Brooks et al (2016a,b) ; EDGE of Existence, www.edgeofexistence.org/, (Safi et al., 2013); (Tonini et al., 2016)); (Yessoufou et al., 2017); (Daru et al., 2013).*

Taxonomic group	Cycads	Amphibians	Corals	Mammals	Birds	Squamates
Global non-imperiled PD	3,081	105,803	4,164	30,970	67,537	112,301
Imperiled PD, species in Europe and Central Asia	266	2,031	74	487	442	468
Imperiled PD, species not in Europe and Central Asia	5,510	42,114	1,533	10,104	9,171	9,709
Total imperiled PD / total PD	0.652	0.294	0.278	0.255	0.125	0.083

The table (and all such similar tables) shows an expected serious loss of maintenance of options based on the large fractions of PD that is imperiled. The imperiled PD allocated to individual regions is a portion of the overall tabulated global imperiled PD for the given group, based on the estimated number of threatened species found within that region. For example, the Asia-Pacific region has approximately 38% of the assessed global threatened species (Brooks et al., 2016a) (Brooks et al., 2016b)

Note that the maintenance of options NCP for an individual region depends not only on its own biodiversity but also that of the other regions – for example, Europe and Central Asia benefits from the discovery of the anti-bacterial compound in the Tasmanian devil, recently discovered in the Asia Pacific region.

18.4. Impacts on good quality of life

NCP18 contributes to human well-being to the extent that we appreciate the services and benefits that it insures (insurance value) or preserves for future appreciation or discovery (option value). In the insurance case, this is easier – we can in principle see the benefits now, and value them if we choose, and so see the gains from having insurance. In the option case, we can retrospectively see surprising benefits, and this can promote high value of biodiversity options because of the prospects for more of these surprises (see below). Even more importantly NCP18 means that biodiversity itself – not just the benefits it happens to provide – is critical to appreciate and preserve for those future options.

Insurance

The ability of biodiversity to help maintain current benefits for humans is well known in a variety of contexts.

1. Genetic diversity enables populations and species to persist in the face of environmental change through “evolutionary rescue” (Carlson et al., 2014). In fact, the continued persistence of every population on earth will require genetic variation to adapt to future environmental change (Hendry, 2017).Thus, the maintenance of all future benefits provided by organisms for humans depends on the insurance provided by genetic diversity.

2. The phylogenetic (evolutionary) and functional diversity of the species in a community influences the resilience of that entire community to various disturbances, such as biological invasion or climate change.

In closing, we can turn to (Bruford et al., 2017): “The value of genetic resources includes their capacity to generate ecosystem services, including supporting landscape-level ecosystem resilience (Hajjar et al., 2008); (Narloch et al., 2011), maintaining socio-cultural traditions, local identities and traditional knowledge, and allowing plants and animals to undergo natural evolutionary processes, which in turn generate broad genetic variation essential for adaptation to change (Bellon et al., 2015). Genetic variation contributes directly to agriculture by providing a range of valuable traits and genes that are used by modern day breeders for improvement, in particular those species that are closely related to domesticated forms (Hajjar and Hodgkin, 2007)). Genetic variation also enhances resilience to climate change by providing the traits that are key to the efficiency and adaptability of production systems. It underpins the efforts of local communities and researchers to improve the quality and output of food production (FAO 2015)."

Options

Evidence of the contributions of biodiversity to future quality of life from the perspective of options are not always known in advance because, by definition, they are new benefits in the future that are not known in the present. Thus, the benefits stem from preserving and maintaining biodiversity in the present. However, we can retrospectively realize the massive benefit of this part of NCP18 in the form of every past discovery of a new human benefit from some aspect of biodiversity (Gascon et al., 2016). These include what were – at the time of discovery – new crops, new domesticated animals, new medicines, new materials, and so on. Moreover, new options are coming to light every year, which a few examples were serve to illustrate.

1. (Chassagnon et al., 2017) reported last year that the venom of the "Darling Downs" (Queensland, Australia) funnel web spider (*Hadronyche infensa*) is the unanticipated source for a drug to ward off brain damage caused by strokes.

2. Peel et al (2016) reported that the milk from Tasmanian devils provides a weapon against antibiotic-resistant bacteria.

3. Honeycomb moth caterpillars can eat through (Bombelli et al., 2017). The caterpillars are beeswax-eating pests, but enzymes from the caterpillars provide an un-expected global benefit.

4. Golden jackals (*Canis aureus*), long regarded as a pest, are now known to be a remover of domestic animals carcasses, which is saving ca. 2 million euros in Europe (Ćirović et al., 2016)

The appreciation of option values of biodiversity also can be assessed through the valuation of genetic diversity by pharmaceutical companies or agricultural/livestock enterprises.

In closing, we can again turn to (Bruford et al., 2017) arguments for the value of genetic diversity: "As raw material for biotechnology, global genomic biodiversity provides a rich source of 'parts' for synthetic biology fuelling the new bio-economy. Molecular solutions discovered over the eons will help humanity address grand societal challenges of the 21st century regarding food, energy, water, and health. For example, crop genetic diversity has a critical role in addressing food and nutrition security, continually increasing yield from crops and livestock (on smaller land space), and instilling resilience to climate change (Dulloo et al., 2014); (Hajjar et al., 2008); FAO 2015)."

18.4.1. Indicators of NCP impact

The NCP18 impact on well-being involves one aspect of value akin to "relational value" (for discussion see Faith 2017). NCP18 is providing a benefit or contribution in the sense that society has the satisfaction of maintaining options for future generations, and this satisfaction links to a relational value between generations. Beyond this, every new (option) or maintained (insurance) drug, product, resource, or crop provided by biodiversity generates an impact of NCP18 on human well-being.

18.5. Summary

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 as the results of new discoveries can be applied anywhere. Species extinction rates are estimated to be 1000 times background extinction rates (Pimm et al. 2014). We are losing many populations and species 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 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).

	Potential Nature's Contributions
Indicator	
Trend During the last 50 years: 2 = Major increase (>20%) 1 = Increase (5% to 20%) 0 = No change (-5% to 5%) -1 = Decrease (-20% to -5%) -2 = Major decrease (< -20%)	-1 to -2 Indicators: (a) loss of species; (b) loss of phylogenetic diversity (PD) Species extinction rates are estimated to be 1000 times background extinction rates, which are rates without added anthropogenic threats (Pimm et al. 2014) "vertebrate species, 32% (8,851/27,600) are decreasing; that is, they have decreased in population size and range. In the 177 mammals for which we have detailed data, all have lost 30% or more of their geographic ranges and more than 40% of the species have experienced severe population declines (>80% range shrinkage)." Ceballos et al. 2017 By 2016, 559 of the 6190 domesticated breeds of mammal were recorded as extinct (including 182 breeds of cattle, 160 of sheep and 108 of pig), as well as 84 of the 2632 domesticated breeds of bird (including 62 chicken breeds and 15 breeds of duck) (FAO 2016). A further 1500 breeds (999 mammals and 501 birds) are currently threatened with extinction (FAO 2016). These numbers are sure to be under-estimates as the conservation status of 58% of breeds remains unknown (FAO 2016). Measure of loss of PD: 6.5% - 8% (depending on taxonomic group) have imperiled phylogenetic diversity (Faith et al. 2018).
Spatial variance	2

3 = opposite trends in different regions 2 = same directional trends in different regions but of contrasting magnitude 1 = similar trends all over the world	
Variance across user groups 3 = opposite trends for different groups 2 = same directional trends for different groups but contrasting magnitudes 1 = similar trends for all social groups	NA
Degree of certainty 4 = **Well established**: Robust quantity and quality of evidence & High level of agreement 3 = **Established but incomplete**: Low quantity and quality of evidence & High level of agreement 2 = **Unresolved**: Robust quantity and quality of evidence & Low level of agreement 1 = **Inconclusive**: Low quantity and quality of evidence & Low level of agreement	3 The trends are based on hard data – as noted above – but the places and species for diversity loss is highest are not well established. The trends are clear but a lot of species are "data deficient"
Two to five most important papers supporting the reported trend	1. Ceballos, Gerardo, Paul R. Ehrlich, and Rodolfo Dirzo. Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. Proceedings of the National Academy of Sciences 114.30 (2017): E6089-E6096. 2. Faith DP et al. 2018. Indicators for the Expected Loss of Phylogenetic Diversity. In: (R. Scherson and D.P. Faith eds.) 3. Pimm, S.L. et al. 2014. The biodiversity of species and their rates of extinction, distribution, and protection. *Science* 344, 1246752 (2014). DOI: 10.1126/ science.1246752

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18.7. Search methodology

We did not use a specific search methodology.