Figure 3 11 **A global map of the land-grabbing network: land-grabbed countries (green disks) are connected to their grabbers (red triangles) by a network link.**

Relations between grabbing (red triangles) and grabbed (green circles) are shown (green lines) only when they are associated with a land grabbing exceeding 100,00 ha. Source: Rulli *et al.* (2013).

WHERE ENVIRONMENTAL ACTIVISTS WERE KILLED 2010 TO 2015

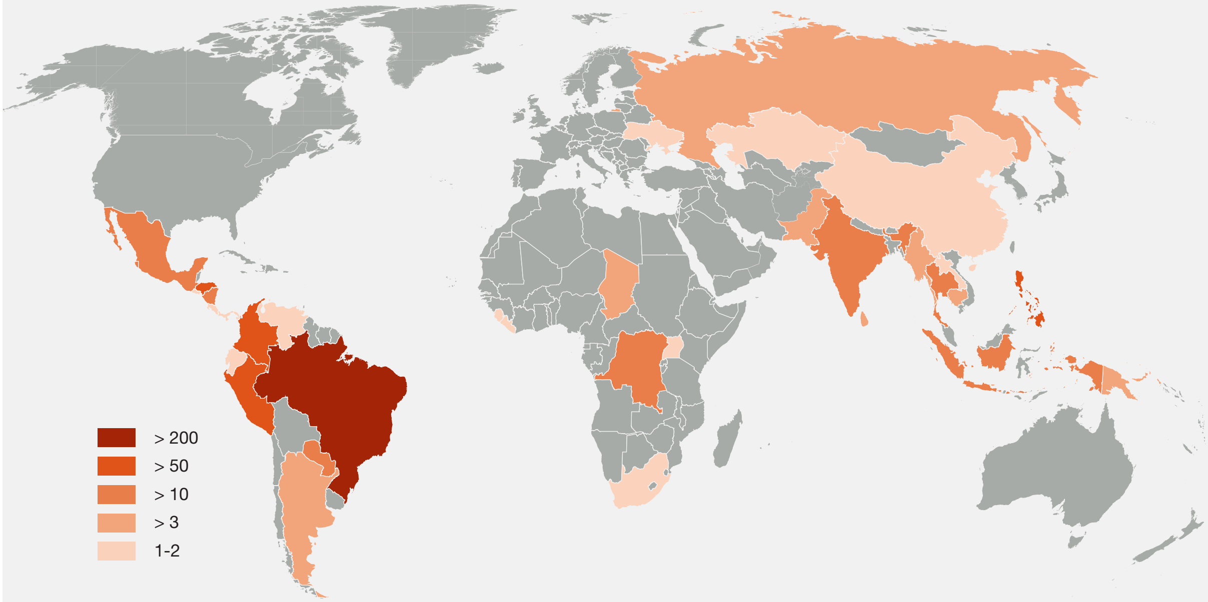


Figure 3 12 **Number of reported deaths of environmental activists during 2010-2015.**

Source: https://www.globalwitness.org/en/.

and tighten national and international cooperation to combat illegal wildlife trade (target 16.6) many populations of endangered species will continue to decline in the wild. Illegal trade in wildlife products has also been linked to financing the activities of militant groups and catalyzing social conflict (Douglas & Alie, 2014) and as the scarcity of rare and endangered species becomes more apparent, their rarity is likely to fuel more demand, increasing the potential for overexploitation and intensifying conflict dynamics.

In terms of enhancing the role of justice in the governance of nature and NCP, this has mainly been looked at in relation to addressing issues linked with inequality with a particular focus on more inclusive and fair protected area management by focusing on issues related to recognition (Martin *et al*., 2016), social justice (Vucetich *et al*., 2018), understanding and managing conservation conflicts (Redpath *et al*., 2012) and better understanding the role of social equity (Friedman *et al*., 2018). Notions of justice and nature have also been increasingly integrated in urban planning processes (see SDG 11.7), especially in relation to urban nature and NCP and their role in building resilience and addressing inequities (Dearing *et al*., 2014; Graham & Ernstson, 2012; Ziervogel *et al*., 2017).

3.3.2.4 Cluster 4: Drivers (Goals 7, 8, 9, 12)

Several SDGs have the potential to be negative or positive drivers of change in nature and NCP, depending on the pathways that are chosen to achieve them. Impacts from particular activities and economic sectors on nature and NCP, as well as trends in all of these, are detailed in chapter 2. Here, we briefly summarize how nature and NCP may be positively or negatively impacted by these SDGs.

SDG 7: Affordable and clean energy

Achievement of targets under SDG 7 can have both positive and negative impacts on nature and NCP. Clean energy should help to mitigate the impacts of climate change, which would have positive impacts on several SDGs including SDGs 1, 2, 3, 6, 13, 14, and 15. Key pathways to achieving clean energy will include developing wind, wave, and water-based (hydropower) energy projects. These developments can have positive or negative impacts on nature and NCP and related SDGs depending on how they are constructed. Dams can radically alter river flow regimes, affecting the function and productivity of downstream waters, which can negatively impact achieving targets within SDGs 6 and 15 related to aquatic ecosystems. However, recent research has found that careful monitoring of flows can be managed to ensure healthy fish stocks, a key concern for food security in some regions (Sabo *et al*., 2017). If not designed and constructed properly, wind and wave energy projects could affect the achievement of targets under SDGs 14 and 15. Clean energy may also include petroleum development projects, which may still negatively impact reduction of greenhouse gases associated with climate change.

SDG 8: Decent work and economic growth

Nature and NCP can provide pathways to achievement of SDG 8 but can also be positively or negatively impact by policies and measures implemented to achieve them (See SDG 1 for a discussion of economic growth, poverty alleviation and nature). Achievement of Target 8.4 on improvements in global resource efficiency would have strong positive impacts on nature and NCP by decoupling economic growth from environmental degradation. At the same time, nature and NCP provide pathways for achieving economic growth. Effective management of nature and NCP may provide greater employment opportunities and revenue generation. The forestry and fisheries sectors alone are worth at least $583 billion (FAO, 2014b) and $148 billion per year (FAO, 2016), respectively. Employment in sectors that depend on sustainable production in these ecosystems and others can also be critically important to national economies (FAO, 2014b; Jaunky, 2011).

There are recognized needs to initiate reforms in some ecosystem-based sectors to meet Target 8.7 (on ending slavery and child labour) and 8.8 (on labour rights and safe working environments). For example, the need to initiate reforms in the fisheries sector has received increased focus (Kittinger *et al*., 2017) as has the role of companies in improving practices along their supply chain (Österblom *et al*., 2015). Similarly, achievement of Target 8.9 could also have potential positive impacts on nature and NCP through the development of sustainable tourism. Implementation of activities to achieve many other targets under SDG 8 will need to consider how they may have impacts on nature and NCP and whether these can be mitigated or minimized. Future work should also consider the role of nature and NCP in creating decent work in new areas, as well as rights-based approaches to employment and job creation.

SDG 9: Industry, innovation and infrastructure

Achievement of SDG 9 targets can have either positive or negative impacts depending on approach, although the potential for large negative impacts appears high. Efforts to develop quality reliable infrastructure in Target 9.1 could include developing public transportation systems and enhancing rail networks, both of which would have positive impacts in the achievement of SDG 13 by mitigating climate change, with consequent indirect positive impacts on SDGs 6, 14, and 15. However, indicators for Target 9.1 suggest that road-building would also be a major aspect of achieving Target 9.1. Roads can be a major source of habitat fragmentation with negative impacts for ecosystems (Pfeifer *et al*., 2017) and species like birds and mammals (Benitez-Lopez *et al*., 2010). Roads are also associated with increased deforestation in the Amazon (Barber *et al*., 2014). Similar potential positive and negative impacts could be associated with the development pathways that may be chosen for Targets 9.2 (promote sustainable industrialization) and 9.3 (increase access of small-scale industries to financial services). Target 9.4 (upgrade infrastructure and retrofit industries to make them more sustainable) is likely to have positive impacts on nature and NCP by making industries more sustainable and cleaner, with lower CO_2 footprints. Achievement of Target 9.5 (Enhance scientific research and upgrade technological capabilities of industrial sectors) may also have positive impacts through the development of technology that reduces industrial footprints, identifies opportunities for circular economies, or improvement to supply chains.

SDG 12: Responsible consumption and production

Meeting the targets under Goal 12 has the significant potential to have positive impacts on nature and NCP by changing production and consumption patterns. Target 12.2 on resource use, target 12.4 on waste management, target 12.7 on procurement practices, and target 12.8 on information and awareness of sustainable development are particularly relevant to efforts to conserve and sustainably manage nature and NCP.

Target 12.2 is fundamental to the notion of sustainable development and development's reliance on renewable and non-renewable land, ocean, water and nature resources. Their exploitation is linked to positive impacts on well-being on average, but negative implications for nature and NCP, as well as unequal and negative impacts on certain groups, places and generations (WSSD, 2002). The scale of human impacts now implies that the effects of not achieving this target will be globally realized e.g., through climate change, shifts in biogeochemical pollutant loads and the loss of biosphere resilience (Steffen *et al*., 2015). This target has overlaps with several targets in SDG 15 on conservation, sustainable management and resource use. The concept of efficient use has some potential but requires clarification and standards emerging from fields such as Life Cycle Analysis and others in order to make it measurable and the challenges of incommensurability of inputs and outputs may prove an obstacle. This would be challenging especially in the light of IPBES's embrace of multiple values implying that an economic analysis to efficiency would be insufficient.

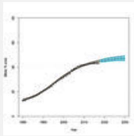
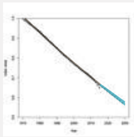
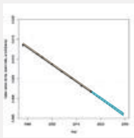
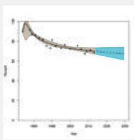
Target 12.4 on waste management is an area likely to have many positive implications on nature and NCP as well as GQL of all people. Currently waste, through its impacts on air and water quality, has negative impacts on well-being, especially in poor and vulnerable communities. This target relates closely to SDGs 6, 14, and 15, as well as aspects of SDG 3 and 11, in terms of trends in pollution and its impacts on health and the environment. Recent work on chemical pollution has highlighted what are referred to as "novel entities" – created entirely by humans e.g., synthetic organic pollutants, radioactive materials, genetically modified organisms, nanomaterials, and microplastics. These have important implications for nature and people, they can exist for a very long time, and their effects are potentially irreversible (Steffen *et al*., 2015).

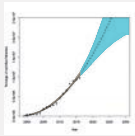
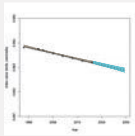
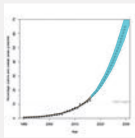
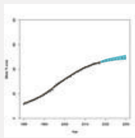
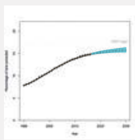
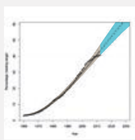
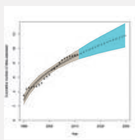
Target 12.7 focuses on public procurement which is widely recognized as a way to achieve GQL outcomes, including those linked to sustainability (McCrudden, 2004). There have been documented successes in terms of addressing equality and human rights (McCrudden, 2004). Achievement of this target could benefit nature and NCP by only sourcing materials that were harvested sustainability or produced with minimal impact in the supply chains used by public entities. The considerable buying power and scope of these purchases have the potential to transform supply chains even for non-public entities. Previous estimates of the scale of public procurement suggest that 8–25% of the gross domestic product of Organisation for Economic Cooperation and Development (OECD) countries and 16% of European Union (EU) GDP are attributable to government purchases of goods or services (Brammer & Walker, 2011). Green public procurement is a "demand side" policy that functions by creating the demand for sustainable produced products (Cheng *et al*., 2018). Achievement of this target could have direct positive impacts on nature and NCP and therefore on SDGs 6, 14, and 15. Leadership and senior manager support for sustainable green procurement and its inclusion in planning, strategies and goal setting is a major factor in its implementation. Similarly, if government policy and legislation support sustainable procurement, public sector organizations are more likely to implement it. Challenges for sustainable public procurement include the voluntary nature of most policies and practices and competing budgetary constraints (Brammer & Walker, 2011). Sustainable public procurement is still relatively nascent, and research has focused more on implementation than effectiveness, so the scope of potential impacts remains unknown (Cheng *et al*., 2018).

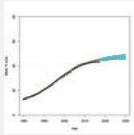
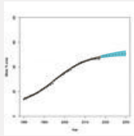
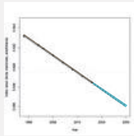
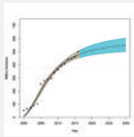
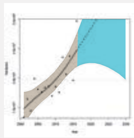
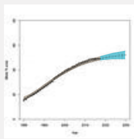
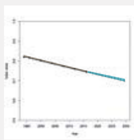
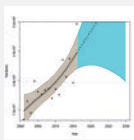
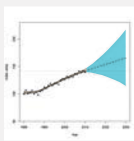
Target 12.8 is similar in aims to Aichi Target 1, on raising awareness of biodiversity and the steps needed to conserve and use it sustainably. As discussed in section 3.2, progress on this issue has so far been insufficient, but is increasing, although these findings largely related to awareness of biodiversity values **(Table 3.3)**. There is currently little evidence as to progress on public awareness and information on sustainable development, suggesting it has not yet had large-scale general uptake. SDG 4 is also relevant and is discussed above under the GQL cluster.

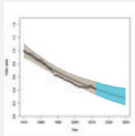
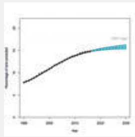
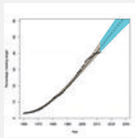
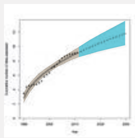
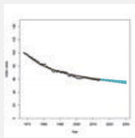
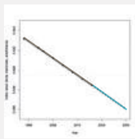
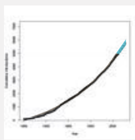
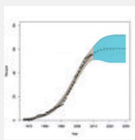
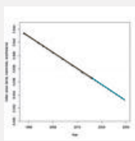
Table 3 7 **Trends of indicators extrapolated to 2030 to assess progress towards Sustainable Development Goals 6, 14 and 15 and their targets that are most closely related to nature and its contributions to people.**

Targets listed in red had no indicators suitable for extrapolation. Larger format versions of the thumbnail graphs, which include y-axis labels and background information on each indicator, are provided in Table S3.6.

SDG	Target	Indicator name	Alignment	Projected trend (2010-2030)	Graph
CLEAN WATER & SANITATION	**6.3** By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally				
	6.4 By 2030, substantially increase water-use across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity				
	6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate				
	6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	Percentage of freshwater Key Biodiversity Areas covered by protected areas*	High	Significant increase	
		Wetland Extent Trends Index	Medium	Significant decrease	
LIFE BELOW WATER	**14.1** By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution	Red List Index (impacts of pollution)	Low	Significant decrease	
	14.2 By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans				
	14.3 Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels				
	14.4 By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics	Proportion of fish stocks in safe biological limits*	High	Non-significant decrease	

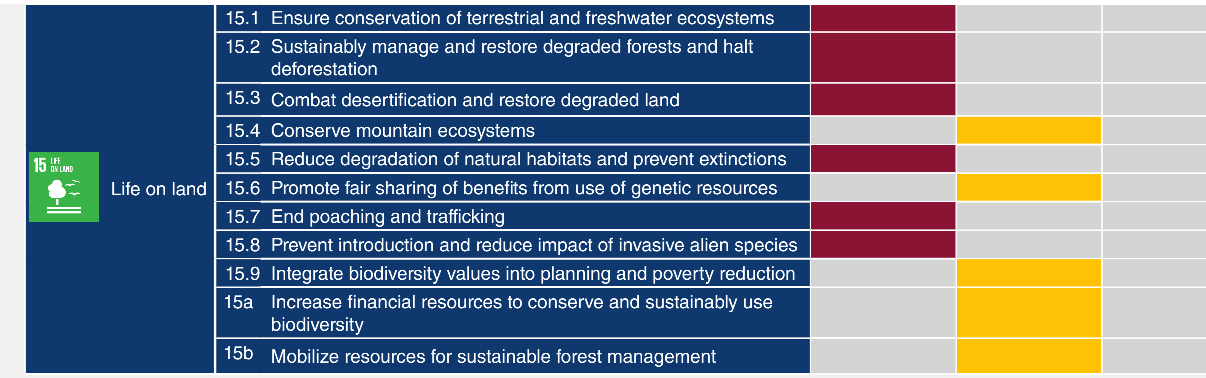
SDG	Target	Indicator name	Alignment	Projected trend (2010-2030)	Graph
		Marine Stewardship Council engaged fisheries (tonnes)	High	Significant increase	
		Red List Index (impacts of fisheries)	Medium	Significant decrease	
	14.5 By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information	Percentage of marine and coastal areas covered by protected areas*	High	Significant increase	
		Percentage of marine Key Biodiversity Areas covered by protected areas	High	Significant increase	
	14.6 By 2020, prohibit certain forms of fisheries subsidies which contribute to overcapacity and overfishing, eliminate subsidies that contribute to illegal, unreported and unregulated fishing and refrain from introducing new such subsidies, recognizing that appropriate and effective special and differential treatment for developing and least developed countries should be an integral part of the World Trade Organization fisheries subsidies negotiation.				
	14.7 By 2030, increase the economic benefits to small island developing States and least developed countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture and tourism				
LIFE ON LAND	**15.1** By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements	Percentage of terrestrial areas covered by protected areas	High	Significant increase	
		Percentage of terrestrial ecoregions covered by protected areas	Medium	Significant increase	
		Number of protected area management effectiveness assessments	Low	Significant increase	

SDG	Target	Indicator name	Alignment	Projected trend (2010-2030)	Graph
		Percentage of freshwater Key Biodiversity Areas covered by protected areas*	High	Significant increase	
		Percentage of terrestrial Key Biodiversity Areas covered by protected areas*	High	Significant increase	
		Red List Index (impacts of utilization)	High	Significant decrease	
	15.2 By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally	Area of forest under sustainable management: total FSC and PEFC forest management certification (million ha)	High	Significant increase	
		Area of tree cover loss (ha)	High	Significant increase	
	15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world				
	15.4 By 2030, ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development	Percentage of mountain Key Biodiversity Areas covered by protected areas*	High	Significant increase	
	15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species	Red List Index*	High	Significant decrease	
		Area of tree cover loss (ha)	Medium	Significant increase	
		Climatic Impact Index for Birds	Medium	Significant increase	

SDG	Target	Indicator name	Alignment	Projected trend (2010-2030)	Graph
		Living Planet Index	High	Significant decrease	
		Percentage of terrestrial areas covered by protected areas	High	Significant increase	
		Percentage of terrestrial ecoregions covered by protected areas	Medium	Significant increase	
		Number of protected area management effectiveness assessments	Low	Significant increase	
		Wild Bird Index (habitat specialists)	High	Significant decrease	
	15.6 Promote fair and equitable sharing of the benefits arising from the utilization of genetic resources and promote appropriate access to such resources, as internationally agreed				
	15.7 Take urgent action to end poaching and trafficking	Red List Index (impacts of utilization)	Medium	Significant decrease	
	15.8 By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species	Number of invasive alien species introductions	High	Significant increase	
		Percentage of countries with invasive alien species legislation	High	No significant change	
		Red List Index (impacts of invasive alien species)	High	Significant decrease	

SDG	Target	Indicator name	Alignment	Projected trend (2010-2030)	Graph
	15.9 By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts				
	15.a Mobilize and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems				
	15.b Mobilize significant resources from all sources and at all levels to finance sustainable forest management and provide adequate incentives to developing countries to advance such management, including for conservation and reforestation				

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



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

Figure 3 13 **Summary of recent status of, and trends in, aspects of nature and nature's contributions to people that support progress towards achieving selected targets of the Sustainable Development Goals.**

Selected targets are those where current evidence and target wording enable assessment of the consequences for target achievement of trends in nature and nature's contribution to people. Chapter 3 section 3.3 provides a goal-level assessment of the evidence of links between nature and all Sustainable Development Goals. Scores for targets are based on systematic assessments of the literature and quantitative analysis of indicators where possible. None of the targets scored 'Full support' (that is, good status or substantial positive trends at a global scale); consequently, it was not included in the table. 'Partial support': the overall global status and trends are good or positive but insubstantial or insufficient, or there may be substantial positive trends for some relevant aspects but negative trends for others, or the trends are positive in some geographic regions but negative in others; 'Poor/Declining support': poor status or substantial negative trends at a global scale; "Uncertain relationship": the relationship between nature and/or nature's contributions to people and achieving the target is uncertain; "Unknown": insufficient information to score the status and trends.

3.3.3 The Sustainable Development Goals and Indigenous Peoples and Local Communities

In this section, we review the role of IPLCs in efforts to achieve the SDGs, their contributions to progress to date, and the implications of achieving the SDGs to IPLCs. We focus primarily on the positive contributions that IPLCs make to achieve SDGs and their targets, but recognize that there are exceptions, some related to differing worldviews, and note some of these in the text. IPLCs have participated in meetings held under CBD and other international initiatives such as UNPFII, EMRIPS and the special rapporteur on Indigenous Peoples' rights. However, overall, Indigenous Peoples' participation at the UN level has been smaller than desirable. National dialogue on the Sustainable Development Goals (SDGs) between Indigenous Peoples and governments has also very limited in most countries (AIPP *et al*., 2015). Indigenous Peoples are mentioned only six times in the SDGs, and only in two targets (2.3, 4.5), which has been seen as a major disappointment for IPLCs (AIPP *et al*., 2015), UN Environment, 2015), although the lack of mentions elsewhere does not limit application of the broader goals and targets to their specific contexts. While a lot of the themes promoted and advocated by Indigenous Peoples in recent years have been included in the 2030 Agenda, the SDGs lack attention to issues such as the importance of free, prior and informed consent, and potential conflicts between the economic growth goals of the agenda and the environmental and social goals. an opportunity to use the SDGs to continue advances (AIPP *et al*., 2015). Weak participation in setting the goals hampers IPLCs ability to monitor and assess progress.

SDG 1: End poverty in all its forms everywhere

Indigenous Peoples are accounted as the poorest of the world's poor (Hall & Patrinos, 2012; Macdonald, 2012). Moreover, poverty is higher in rural remote areas (Ahmed *et al*., 2007; Sunderlin *et al*., 2005) and areas of importance for biodiversity conservation (Fisher & Christopher, 2007), where most IPLCs live. Nevertheless, IPLCs have a threefold contribution to poverty eradication. First, IPLCs are the main actors in the so-called win-win initiatives (or triple benefit; Brockington & Duffy, 2011) aimed at biodiversity conservation and climate mitigation while improving income level (e.g., Adhikari *et al*., 2004; Ahenkan & Boon, 2010; Brown *et al*., 2011; Campos-Silva & Peres, 2016; Chirenje, 2017; Dulal *et al*., 2012; El Bagouri, 2007; Roe, 2008). Second, IPLCs traditional institutions (e.g., taboos; Cinner *et al*., 2009), ILK and management practices (e.g., diversification) help mitigate the effects of poverty and vulnerabilities (Aryal *et al*., 2014) and to adapt to natural disasters and global changes (Ingty, 2017; Parraguez-Vergara *et al*., 2016). Third, interventions among IPLCs have contributed to the debate on whether poverty definitions based on monetary indicators are adequate (Fukuda-Parr, 2016). IPLCs often have different understandings of what poverty or wealth are (Chambers, 2005), rely on non-monetary sources of wild natural resources (Angelsen *et al*., 2014; Ehara *et al*., 2016; Robinson, 2016), and face multiple stressors (Gratzer & Keeton, 2017), or multidimensional poverty. Given that conservation and development interventions occasionally coincide with the loss of access to land and resources (e.g., Asquith *et al*., 2002), income (e.g., L'Roe & Naughton-Treves, 2014), and traditional livelihoods and culture (Mbaiwa *et al*., 2008) alternative approaches to monetary assessments of poverty have been devised for understanding and guiding policymaking (Bridgewater *et al*., 2015) and environmental policy frameworks (e.g., in REDD+ safeguards; Arhin, 2014) addressed to IPLCs. As remote rural inhabitants rely substantially on natural resources, increased access to monetary income may affect IPLC livelihoods, while also impacting biodiversity in multiple ways (Godoy *et al*., 2005), not necessarily taking pressure off natural resources (Angelsen *et al*., 2014). Moreover, the evidence regarding integrated conservation and poverty alleviation initiatives has been mixed and sometimes poorly quantified (Charnley & Poe, 2007; Romero-Brito *et al*., 2016). Restricting IPLCs' rights on forest products harvest and trade has precluded opportunities for income generation (e.g., Mbaiwa *et al*., 2008; Scheba & Mustalahti, 2015), or lowered cash income (e.g., Katikiro, 2016). Government and non-government development projects have frequently neglected IPLCs' rights and knowledge and have not adequately addressed asymmetric relations and inequities in their access to economic and political opportunities (Reyes-Garcia *et al*., 2010). Government-led poverty-alleviation programs are not necessarily adapted to IPLCs, sometimes being culturally inaccessible to indigenous families (Zavaleta *et al*., 2017).

SDG2: Zero Hunger

IPLCs have developed a variety of systems to achieve local food security through sustainable use of the environment. For example, research shows that traditional farming systems that exploit biodiversification, soil and water management have helped IPLCs to achieve food security through sustainable agricultural production (Altieri & Nicholls, 2017; Bjornlund & Bjornlund, 2010). Similarly, sustainable forest management, agroforestry, wild edible plant collection (Appiah & Pappinen, 2010; Boscolo *et al*., 2010; Ciftcioglu, 2015; Takahashi & Liang, 2016) and small-scale fisheries (Ali *et al*., 2017) have also played a vital role in IPLCs' food security. However, malnutrition and under nourishment among children under five years old is major problem among some IPLCs, particularly after they lose access to their lands and traditional livelihoods (Anticona & Sebastian, 2014; Babatunde, 2011; Dutta & Pant, 2003; Ferreira *et al*., 2012; Gracey, 2007). Moreover, dietary transitions affecting IPLCs are leading to increasing rates of overweight, obesity and associated chronic diseases, known as "hidden hunger" (Crittenden & Schnorr, 2017; Ganry *et al*., 2011; Kuhnlein *et al*., 2006, 2009; Popkin, 2004). Scientists now recognize that many food production systems developed by IPLCs could contribute to sustainable food production (Altieri & Nicholls, 2017; Barrios *et al*., 2015; Campos-Silva & Peres, 2016; Kahane *et al*., 2013; Pauli et. al 2016; Winowiecki et. al. 2014). However, it is also acknowledged that the success of programs integrating insights from those systems remains dependent on rights and access allocation, corruption, lack of local financial, intellectual and innovative capacity and centralized governance (Ferrol-Schulte *et al*., 2013), for which policies to fight hunger need addressing not only technical measures, but also tackling power asymmetries that reduce access to land and other resources for IPLCs (Francescon, 2006; Beckh *et al*., 2015) or raising investment in capital and organizational infrastructure (Godfray *et al*., 2010).

SDG 3: Ensure healthy lives and promote well-being for all at all ages

While most contemporary peoples have plural medical systems, traditional medicine continues to play an important role among IPLCs (Cartaxo *et al*., 2010; Chekole, 2017; Cox, 2004; Moura-Costa *et al*., 2012; Padalia *et al*., 2015; Paniagua-Zambrana *et al*., 2015; Tolossa *et al*., 2013). Limited access to other healthcare systems makes traditional medicine the only treatment option in certain communities (Paniagua-Zambrana *et al*., 2015; Tolossa *et al*., 2013); however, traditional medicine can be the preferred treatment option even when other healthcare systems are accessible (Padalia *et al*., 2015). Medicinal ILK has contributed to the discovery of active principles for drug development to treat non-communicable and infectious diseases, including AIDS, neglected tropical diseases, hepatitis, and water-borne diseases (Cartaxo *et al*., 2010; Johnson *et al*., 2008; Moura-Costa *et al*., 2012; Padalia *et al*., 2015; Tolossa *et al*., 2013; Rullas *et al*., 2004). This use, however, has often neglected IPLCs' contributions, giving raise to conflicts over unfair appropriation of ILK (Nelliyat, 2017). Research has shown higher rates of mortality and morbidity among Indigenous Peoples than among their non-indigenous counterparts (Anderson *et al*., 2016; Coimbra *et al*., 2013; Hernandez *et al*., 2017; Hurtado *et al*., 2005). Nutritional transitions have also resulted in a high prevalence and incidence of obesity, diabetes, and poor nutrition among many IPLCs (e.g., Corsi *et al*., 2008; McDermott *et al*., 2009; Port Lourenco *et al*., 2008; Rosinger *et al*., 2013) as well as high rates of alcohol use and tobacco smoking (Kirmayer *et al*., 2000; Natera *et al*., 2002; Wolsko *et al*., 2007). Given IPLCs' direct dependence on the environment to cover their material (e.g., water, food, shelter and medicines) and cultural needs (e.g., spiritual beliefs and worldviews), environmental changes (e.g., climate change, chemical contamination, land use changes) threaten to jeopardize the achievement of SDG3 for IPLCs (Anderson *et al*., 2015; Aparicio-Effen *et al*., 2016; Bradford *et al*., 2016; Dudley *et al*., 2015; Genthe *et al*., 2013). ILK can aid in the development of local strategies to cope with environmental factors that might put at risk IPLCs' health (Negi *et al*., 2017; Rahman & Alam, 2016), and there exists a handful of community-based interventions aimed at controlling infectious diseases in a sustainable, environmentally friendly way (Andersson *et al*., 2015; Arunachalam *et al*., 2012; Ledogar *et al*., 2017). Some researchers argue for the need to create new indicators of indigenous health that are socially and culturally sensitive and that adopt a more holistic and integrated approach, capturing IPLC definitions of health and well-being (Malkina-Pykh & Pykh, 2008; McMhom, 2002; Zorondo-Rodriguez *et al*., 2014) and addressing the causes of inequalities (Hernandez *et al*., 2017; WHO, 2013).

SDG 6: Clean Water and Sanitation

There is well established evidence that IPLCs have developed complex customary institutions for governing and managing freshwater resources in sustainable ways (e.g., Boelens, 2014; Strauch *et al*., 2016; Tharakan, 2015; Weir *et al*., 2013). Many studies have shown the strong cultural and spiritual ties between IPLCs and freshwater bodies (e.g., lakes, rivers and lagoons), which are deeply rooted in cultural beliefs and social practices and are thus at the basis of IPLC customary institutions for water management (e.g., Anderson *et al*., 2013; Dallmann *et al*., 2013; Jaravani *et al*., 2017; McGregor 2012). ILK-based water management systems are diverse, and include time-honored practices such as rainwater harvesting (Oweis, 2014; Widiyanti & Dittmann, 2014), small-scale sand dams (Lasage *et al*., 2008, 2015), water tanks (Ariza-Montobbio *et al*., 2007; Reyes-García *et al*., 2011), traditional water purification methods (Mwabi *et al*., 2013; Opare, 2017), forestry-based groundwater recharge (Camacho *et al*., 2016; Everard *et al*., 2018; Strauch *et al*., 2016), and complex systems of river zonation (e.g., Tagal System in Malaysia; AIPP, 2015; Halim *et al*., 2013). Additionally, several water-smart agricultural practices have been deemed effective at simultaneously ensuring water availability and conservation of biodiversity (Hughey & Booth, 2012; Lasing, 2006; Reyes-García *et al*., 2011). The strong cultural connections that IPLCs maintain with their freshwater bodies have allowed them to closely monitor water availability and quality (Alessa *et al*., 2008; Bradford *et al*., 2017; Sardarli, 2013). There is well established evidence that water insecurity disproportionately impacts IPLCs (Medeiros *et al*., 2017; Lam *et al*., 2017), resulting in multiple adverse health, economic and sociocultural burdens (e.g., Daley *et al*., 2015; Henessy & Bressler, 2016; Sarkar *et al*., 2015). Research shows that IPLCs have systematically lower access to clean water supplies than other segments of the population (Baillie *et al*., 2004; McGinnis & Davis, 2001; Ring & Brown, 2002), leading to high prevalence of several infectious diseases (Anuar *et al*., 2016; Han *et al*., 2016; Stigler-Granados *et al*., 2014). Moreover, environmental pollution (Bradford *et al*., 2017; Dudarev *et al*., 2013) and climate change (Dussias, 2009; Ford *et al*., 2014; Nakashima *et al*., 2012) exacerbate ongoing threats to the water supplies of IPLCs. IPLCs are also some of the most vulnerable groups to the impact of large-scale water resource development projects (Finn & Jackson, 2011; King & Brown, 2010), including dams and irrigations plans (Dell'Angelo *et al*., 2017; Winemiller *et al*., 2016). IPLCs have often been excluded from water decision-making bodies (Finn & Jackson, 2011; Hanrahan, 2017; Weir, 2010), as narrow conceptualizations of IPLCs water rights limit their ability to sustainably manage water resources according to traditional responsibilities (Durette, 2010; Tan & Jackson, 2013). Low participation of IPLCs in water management bodies has often fueled water conflicts and disagreement over the most culturally-appropriate policy options to ensure availability and sustainable management of water (Jiménez *et al*., 2015; Trawick, 2003). If interventions aimed at improving the role of indigenous water management systems are to be effective, water resource planners need to consider not only technical but also sociocultural factors (Dobbs *et al*., 2016; Jaravani *et al*., 2016; Pahl-Wostl *et al*., 2007; Reyes-García *et al*., 2011), including greater respect towards ILK and IPLC cultural values (Henwood *et al*., 2016; Maclean & The Bana Yarralji Bubu Inc. 2015; Tipa, 2009).

SDG 11: Sustainable cities and communities

It is increasingly acknowledged that IPLCs can contribute to enhance urban sustainability in aspects such as efficient water and energy consumption, reducing waste production and improving its disposal, reducing urban carbon footprints, and making urban agriculture more sustainable (e.g., Cosmi *et al*., 2016; Barthel *et al*., 2010; Langemeyer *et al*., 2017; Mihelcic *et al*., 2007; Schoor *et al*., 2015). IPLCs can also contribute to social-ecological resilience and to a sustained flow of ecosystem services in urban contexts under change (Andersson & Barthel, 2016; Hurlimann *et al*., 2014), as shown in examples from European cities during World Wars I and II (Barthel *et al*., 2015) and Havana, Cuba, after the end of the Soviet Union (Altieri *et al*., 1999). IPLCs can make cities safer by improving disaster risk detection and management, for which scholars have defended the importance of integrating ILK into risk assessment and management programs (Arriagada-Sickinger *et al*., 2016; Zweig, 2017). IPLCs and ILK are increasingly being valued in sustainable urban planning and design (Bunting *et al*., 2010; Young *et al*., 2017), but there is a further need to continue to do so, for which efficient methods are emerging (Kyttä *et al*., 2013, 2016; Samuelsson *et al*., 2018). Yet, researchers have also argued that IPLCs alone are not sufficient to create critical urban resilience, underscoring the need for functioning institutions to support IPLCs (Walters, 2015).

SDG 12: Responsible consumption and production

The existing body of academic research on IPLCs and responsible production and consumption is illuminating on three issues that not only affect IPLCs but are also obstacles for sustainable development. First, there is much heterogeneity between people with regards to drivers and consequences of resource use expansion linked to unsustainable production and consumption (Pichler *et al*., 2017). Through their low degree of involvement with mass production and consumption, IPLCs are not a driving force of the global environmental change from which they nevertheless disproportionally suffer (Chance and Andreeva, 1995; Martinez-Alier, 2014; Smith and Rhiney, 2016; Tsosie, 2007). Second, power disparities play a critical role in the appropriation of natural resources, including via the appropriation of ILK. As the resource frontier is continuously expanded for economic growth and increased production and consumption, encroachment on IPLCs' land has become widespread (e.g., Finer *et al*., 2008; Pichler, 2013), commonly threatening livelihoods (Bunker, 1984; Gerber, 2011; Larsen *et al*., 2014; Mingorría *et al*., 2014). In this economic model, the power of IPLCs to determine resource use is severely restricted (Benda-Beckmann & Benda-Beckmann, 2010, Devine & Ojeda, 2017; Li, 2001, 2010; Watts and Vidal, 2017). Notwithstanding this, the appropriation of ILK is considered pivotal in attaining more sustainable management of resources (e.g., Fearnside, 1999; Gadgil *et al*., 1993; Johannes *et al*., 2000; Véron, 2001). Published research has focused very strongly on integrating ILK into the existing capitalist system of production and consumption (Donovan and Puri, 2004; Ilori *et al*., 1997; Kahane *et al*., 2013; Sarkar, 2013; Usher, 2000) with its reliance on growth through the appropriation of resources and labour (Moore, 2015). Integrating ILK into production and consumption may endanger any sustainability benefits (Nadasdy, 1999b). Third, despite the inherent unsustainability of the current resource use trajectory, existing tools for sustainable resource management typically propose the integration of IPLC claims (Fernandez-Gimenez *et al*., 2006; O'Faircheallaigh, 2007), rather than interpreting the (often non-monetary) preferences of IPLCs (Avcı *et al*., 2010; Dongoske *et al*., 2015; Martinez-Alier, 2009) in terms of possible alternative resource use futures (White, 2006). To achieve sustainable production and consumption, greater consideration is needed of alternative visions of what it means to prosper and to live well, rather than in material abundance (Kothari *et al*., 2014; Radcliffe, 2012; Zimmerer, 2015).

SDG 13: Climate Action. Combat climate change and its impacts

It is well established that IPLCs have contributed to mitigation of climate change effects (Campbell, 2011; Gabay *et al*., 2017; Lunga & Musarurwa, 2016), partly because of their low contribution to GHG emissions (Heckbert *et al*., 2012; Russell-Smith *et al*., 2013). Agreement is also growing that ILK can be an alternative source of knowledge in efforts to mitigate and adapt to climate change (Altieri & Nicholls, 2017; Chanza & De Wit, 2016; Eicken, 2010; Magni, 2017; Pearce *et al*., 2015). It is also well acknowledged that IPLCs are among the groups most affected by the impacts of climate change**,** including effects of unexpected extreme rainfall events (Baird *et al*., 2014; Joshi *et al*., 2013), floods (Cai *et al*., 2017), droughts (Kalanda-Joshua *et al*., 2011; Swe *et al*., 2015), pasture disappearance (He & Richards, 2015; Wu *et al*., 2015), extinction of medicinal plants (Klein *et al*., 2014; Mapfumo *et al*., 2016), changes in animal behaviour patterns (Pringle & Conway, 2012), and the spread of pests and invasive alien species (Shijin & Dahe, 2015; Shukla *et al*., 2016). While in the past, ILK had allowed IPLCs to understand weather variability and change, ILK might now be less accurate as weather becomes increasingly unpredictable (Cai *et al*., 2017; Konchar *et al*., 2015). The failure of ILK to detect, interpret and respond to change generates a feeling of insecurity and defenselessness that undermines IPLC resilience and exacerbates their vulnerability (Mercer & Perales, 2010; Simelton *et al*., 2013). The potential of combining ILK and scientific knowledge to design successful climate adaptation policies is increasingly acknowledged (Alessa *et al*., 2016; Altieri and Nicholls, 2017; Austin *et al*., 2017; Boillat & Berkes, 2013; Hiwasaki *et al*., 2014; Ingty, 2017; Kasali, 2011; Mantyka-Pringle *et al*., 2017), although there are few efforts to make IPLCs aware of the scientific approaches being promoted to combat climate change impacts (Fernández-Llamazares *et al*., 2015; Inamara & Thomas, 2017; Shukla *et al*., 2016), and examples of initiatives aiming to integrate ILK into climate policies are still rare (Seijo *et al*., 2105). Increasing the adoption of climate-smart technologies among IPLCs might contribute to strengthen their adaptive capacity (Scherr *et al*., 2012).

SDG 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development

IPLCs have long history of interacting with the oceans and sustainably managing coastal and marine resources (Cordell, 1989; Johannes, 1978; Lepofsky & Caldwell, 2013; Lotze & Milewski, 2004; Spanier *et al*., 2015; Thornton & Mamontova, 2017). IPLCs also have a deep knowledge of marine ecology (McGreer & Frid, 2017; Salomon *et al*., 2007; Savo *et al*., 2017) that can help sustainably manage marine ecosystems, including coral reefs and mangroves (Cinner *et al*., 2006; Datta *et al*., 2012; Thaman *et al*., 2017). However, traditional marine management regimes can also result in intense resources exploitation (e.g., Andreu-Cazenave *et al*., 2017; Islam & Haque, 2004; Ratner, 2006), for which researchers have warned against the uncritical use of ILK (Turner *et al*., 2013; Turvey *et al*., 2010). The continued degradation of marine ecosystems affects the many IPLCs who are dependent on them, affecting food security (de Lara & Corral, 2017; McGreer & Frid, 2017; Robards & Greenberg, 2007; Watts *et al*., 2017) and social and spiritual integrity (McCarthy *et al*., 2014). Moreover, IPLCs also face important social restrictions regarding marine resources use, including fishing and tenure right restrictions (Joyce & Satterfield, 2010; Thornton &

Mamontova, 2017) and coastal lands dispossession by outside interests (e.g., governments, tourist operators) (Bavinck *et al*., 2017; Hill, 2017). While including IPLCs in managing marine resources can help sustainably managing marine ecosystems (Jupiter *et al*., 2014b), this potential is not always recognized (Johnson *et al*., 2016; Jones *et al*., 2017). Moreover, in many areas traditional fishing techniques have been made illegal (Deur *et al*., 2015; Jones *et al*., 2017; Langdon, 2007; von der Porten *et al*., 2016).

SDG 15: Life on land

With an estimated 28% of the world's land surface held by IPLCs (Garnett *et al*., 2018) and 80% of biodiversity found there (FAO, 2017), IPLCs play a substantial role in governing and managing forests, land, and biodiversity. The often long-lasting relationship between IPLCs and terrestrial ecosystems has led to a co-evolution of social and ecological components that has enhanced adaptive capacity, resilience and sustainability (Berkes *et al*., 2000; Folke, 2006; MacLean *et al*., 2013; Pascua *et al*., 2017). IPLCs contribute to the maintenance and enhancement of land-based ecosystems through management practices that focus on ecological processes (Herrmann & Torri, 2009; see also 2.2.4), multiple use (Toledo *et al*., 2003), agroforestry (Suyanto *et al*., 2005), sustainable logging and hunting (Roopsind *et al*., 2017), fire management (Mistry *et al*., 2016), protection and management of culturally significant trees (Genin & Simenel, 2011; Stara *et al*., 2015), and long-term monitoring (Long & Zhou, 2001; Olivero *et al*., 2016). Giving land titles to IPLCs tends to protect forests from large-scale conversion into other land uses (Blackman *et al*., 2017; Chhatre *et al*., 2012; Nepstad *et al*., 2006) and forests that have cultural and religious significance for IPLCs are usually more diverse, denser and harbour larger and older trees than non-sacred forests (Aerts *et al*., 2016; Borona, 2014; Frascaroli *et al*., 2016; Ormsby, 2013; Rao *et al*., 2011). IPLCs directly benefit from biodiversity, for example through the use of wild plants in diet and medicinal purposes (Singh *et al*., 2014). Biodiversity can have a spiritual importance to IPLCs (Torri & Herrmann, 2011). Biodiversity also makes cultural landscapes and agroecosystems more resilient to climate change (Altieri & Nicholls, 2017; Ingty, 2017). Furthermore, non-extractive uses of biodiversity can provide additional income to IPLCs through carbon offsetting (Renwick *et al*., 2014), ecotourism (Gonzalez *et al*., 2008; Sakata & Prideaux, 2013) and intellectual property rights on biodiversity use (Efferth *et al*., 2016). Yet the equitable sharing of these benefits remains a challenge in practice (De Jonge, 2011; Suiseeya, 2014). IPLCs benefit from ecosystem services provided by resilient lands (Sigwela *et al*., 2017) and are particularity vulnerable to land degradation (Ellis-Jones, 1999). The largest body of literature addresses the participation of IPLCs in combating land degradation in relation with externally supported projects and the need to establish effective participation and knowledge co-production schemes (Oba *et al*., 2008; Raymond *et al*., 2010b; Reed *et al*., 2013; Sedzimir, 2011). While there is relatively little literature on how IPLCs can contribute to combat desertification, the existing one shows that IPLCs have also contributed to fight desertification and soil erosion through indigenous initiatives, some of them rooted in a long-term relation with their environment. This includes plant selection for resistance to drought (Gaur & Gaur, 2004), keeping spiritually relevant patches of forest to halt soil erosion (Yuan & Liu, 2009), the construction and maintenance of traditional irrigation systems (Ashraf *et al*., 2016; Ostrom, 1990), traditional knowledge on soil types and conditions (Barrera-Bassols *et al*., 2006) and terrace construction (Boillat *et al*., 2004). IPLCs can play a key role in monitoring land degradation and soil conditions (Forsyth, 1996; Roba & Oba, 2009) and in land rehabilitation (Yirdaw *et al*., 2017).

3.4 PROGRESS TOWARDS GOALS AND TARGETS OF OTHER GLOBAL AGREEMENTS RELATED TO NATURE AND NATURE'S CONTRIBUTIONS TO PEOPLE

There are more than 150 multilateral environmental agreements related to biodiversity, but six are global in scope and pursue biodiversity conservation as a core objective (Gomar *et al.*, 2014). These comprise one framework convention—the 1992 Convention on Biological Diversity (CBD)—and five focused agreements: (1) the 1971 Convention on Wetlands of International Importance Especially as Waterfowl Habitat (the Ramsar Convention on Wetlands); (2) the 1972 Convention Concerning the Protection of the World Cultural and Natural Heritage (WHC); (3) the 1973 Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES); (4) the 1979 Convention on the Conservation of Migratory Species of Wild Animals (CMS); and (5) the 2001 International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA; S3.10). In this section, we review progress towards the goals of the first four of these Conventions, plus the International Plant Protection Convention (IPPC) and the United Nations Convention to Combat Desertification (UNCCD), as the implementation of both of these has a significant impact on biodiversity and livelihoods. Given that the ITPGRFA has not yet adopted a strategic plan with specified objectives, we do not assess progress, but address this Convention in section S3.10. We also address the United Nations Convention on the Law of the Sea (UNCLOS; Articles 61-66; **Box 3.1**), given that all of the others focus solely on the terrestrial realm **(Table 3.8)**, and two polar conventions, given the global consequences of conservation of these two regions: the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) and the Arctic Council's Conservation of Arctic Flora and Fauna (CAFF, **Box 3.2**). The means by which the CBD coordinates efforts with these MEAs is covered in section S3.9.

Table 3.8 summarizes a high-level assessment of the literature on progress towards the goals and strategic objectives of CMS, CITES, Ramsar Convention, UNCCD, WHC, and IPPC. A more rigorous quantitative analysis of indicators for each of the detailed underlying targets, like that employed for the Aichi Biodiversity Targets in section 3.2, is needed to validate these assessments, but is beyond the scope of this chapter.

Table 3 8 **Progress towards achieving the goals of other global agreements related to nature and nature's contributions to people, based on a synthesis of the literature and available information.**

Progress towards goals is scored as Good (substantial positive trends at a global scale relating to most aspects of the element), Moderate (the overall global trend is positive, but insubstantial or insufficient, or there may be substantial positive trends for some aspects of the goal, but little or no progress for others, or the trends are positive in some geographic regions but not in others), Poor (little or no progress towards goal, or movement away from goal; while there may be local/national or case-specific successes and positive trends for some aspects, the overall global trend shows little or negative progress), or Unknown '?' (insufficient information to score progress).

Convention	Goals	Progress
CMS	**Goal 1:** Address the underlying causes of decline of migratory species by mainstreaming relevant conservation and sustainable use priorities across government and society	Moderate
	Goal 2: Reduce the direct pressures on migratory species and their habitats	Poor
	Goal 3: Improve the conservation status of migratory species and the ecological connectivity and resilience of their habitats	Poor
	Goal 4: Enhance the benefits to all from the favourable conservation status of migratory species	?
	Goal 5: Enhance implementation through participatory planning, knowledge management and capacity-building	Moderate

Convention	Goals	Progress
CITES	**Goal 1:** Ensure compliance with and implementation and enforcement of the Convention.	
	Goal 2: Secure the necessary financial resources and means for the operation and implementation of the Convention.	
	Goal 3: Contribute to significantly reducing the rate of biodiversity loss by ensuring that CITES and other multilateral instruments and processes are coherent and mutually supportive.	
RAMSAR	**Goal 1:** Addressing the drivers of wetland loss and degradation	
	Goal 2: Effectively conserving and managing the Ramsar site network	
	Goal 3: Wisely using all wetlands	
	Goal 4: Enhancing implementation	
UNCCD	**Goal 1:** To improve the living conditions of affected populations	
	Goal 2: To improve the condition of affected ecosystems	
	Goal 3: To generate global benefits through effective implementation of the UNCCD	
	Goal 4: To mobilize resources to support implementation of the Convention through building effective partnerships between national and international actors	
WHC	**Objective 1:** Strengthen the Credibility of the World Heritage List, as a representative and geographically balanced testimony of cultural and natural properties of outstanding universal value	
	Objective 2: Ensure the effective Conservation of World Heritage properties	
	Objective 3: Promote the development of effective capacity-building measures, including assistance for preparing the nomination of properties to the World Heritage List, for the understanding and implementation of the World Heritage Convention and related instruments	
	Objective 4: Increase public awareness, involvement and support for World Heritage through Communication	
	Objective 5: Enhance the role of Communities in the implementation of the World Heritage Convention	
IPPC	**Strategic objective A:** To protect sustainable agriculture and enhance global food security through the prevention of pest spread;	
	Strategic objective B: To protect the environment, forests and biodiversity from plant pests	
	Strategic objective C: To facilitate economic and trade development through the promotion of harmonized scientifically based phytosanitary measures	
	Strategic objective D: To develop phytosanitary capacity for members to accomplish objectives A, B and C	

3.4.1 The Convention on the Conservation of Migratory Species of Wild Animals

The CMS (or 'Bonn Convention') is an intergovernmental treaty aimed at conserving terrestrial, marine and avian migratory species throughout their range (CMS, 2017). Signed in 1979 and entering into force in 1983, the Convention is currently ratified by 124 Parties. CMS Parties strive towards strictly protecting threatened migratory species (Appendix I species) and conserving or restoring the places where they live, mitigating obstacles to migration and controlling other factors that threaten them (CMS, 2017). Non-endangered species with unfavorable conservation status (Appendix II species) that would benefit from international cooperation, are also addressed by the Convention. As well as establishing obligations for CMS Parties, the Convention, promotes concerted action among the range states of migratory species (CMS, 2017). CMS's 11th Conference of the Parties adopted the Strategic Plan for Migratory Species 2015–2023 which has five Goals consisting of 16 Targets (CMS, 2014). Indicators for measuring progress towards these are still in development.

Mainstreaming relevant conservation and sustainable use priorities across government and society to address the underlying causes of decline of migratory species (Goal 1) is underway, but progress has been slow. World Migratory Bird Day has been celebrated annually since 2006, with events now held in over 130 countries worldwide stimulating conservation of migratory birds and raising awareness about the need for their conservation (Target 1; Caddell 2013a, CMS, 2016). Other efforts to raise awareness of migratory species and the steps needed to conserve them have included the 'Year of the Bat' (2017) and similar initiatives for gorillas (2007) and dolphins (2009), but the impact of these initiatives on awareness has not been systematically assessed. Little information is available on the degree to which the values of migratory species and their habitats have been integrated into development and poverty reduction strategies and planning processes and incorporated into national accounting (Target 2).

CMS coordinates the development and implementation of multilateral agreements among countries that share migratory species (Caddell 2013b). Migratory waterbirds, seabirds, cetaceans and bats are among the species groups covered by formal protocols concluded under the Convention. In the case of migratory birds, intergovernmental efforts to identify flyways and coordinate action have been highly successful. For most parts of the world, the policies and processes to secure the well-being of flyways is in place, but the challenge lies in implementing them (Boere & Piersma, 2012). Hence, progress has been made towards improving national, regional and international governance arrangements and agreements affecting migratory species, and to make relevant policy, legislative and implementation processes more coherent, accountable, transparent, participatory, equitable and inclusive (Target 3). Insufficient information is available to assess progress towards ending or reforming incentives, including subsidies that are harmful to migratory species, and to developing and applying positive incentives to their conservation (Target 4).

The direct pressures on migratory species and their habitats have not decreased, and may be worsening, meaning we are not progressing towards achievement of Goal 2. Land-use change owing to agriculture is the most significant threat to terrestrial migratory species, affecting nearly 80% of all threatened and near-threatened migratory bird species (Flockhart *et al*., 2015; Kirby *et al*., 2008), while overexploitation and its indirect impacts is the biggest threat to migratory species in the marine environment (e.g., Croxall *et al*., 2012). Habitat conversion and degradation limit the degree to which many species can modify their migratory routes and may increase the threat from climate change (Robinson *et al*., 2009; Studds *et al*., 2017). Forest fragmentation and deforestation in breeding areas has contributed to the declines of Nearctic–Neotropical bird migrants (Bregman *et al*., 2014; Flockhart *et al*., 2015) and Afro-Palaearctic migrants (Vickery *et al*., 2014). In non-breeding areas, the interaction between habitat degradation and climatic conditions (in particular, drought) are also possible factors (Taylor & Stutchbury, 2016; Vickery *et al*., 2014). Infrastructure development including wind turbines, cables, towers and masts can also be a threat, particularly to migratory soaring bird species (Angelov *et al*., 2013; Bellebaum *et al*., 2013; Kirby *et al*., 2008) and migratory bats. Overharvesting and persecution, often illegal, remain serious threats, particularly at key migration locations (Brochet *et al*., 2016, 2017; Harris *et al*., 2011; Ogada *et al*., 2012). Climate change is negatively affecting many bird species already and is expected to exacerbate these pressures (Howard *et al*., 2018) as well as increasing competition between migratory and non-migratory species (Robinson *et al*., 2009). Climate change may have significant negative effects on the population size of 84% of migratory bird species, which is comparable to the proportion affected by all other anthropogenic threats (80%) (Kuletz *et al*., 2014; Robinson *et al*., 2009). Protected areas can help to mitigate some threats, but just 9% of migratory bird species are adequately covered by protected areas across all stages of their annual cycle, compared with 45% of non-migratory species, a pattern driven by protected area placement that does not cover the full annual cycle of migratory species (Martin *et al*., 2007; Runge *et al*., 2015).

The conservation status of migratory species and the ecological connectivity and resilience of their habitats is worsening, meaning that we are moving away from achievement of Goal 3. More than 11% of migratory land- and waterbirds are threatened or Near Threatened on the IUCN Red List (Kirby *et al*., 2008). Since 1988, the Red List Index shows that migratory birds have become more threatened, with 33 species deteriorating sufficiently to move to higher categories of threat on the IUCN Red List, and only six improving in status to qualify for downlisting (Kirby *et al*., 2008). More than half of migratory bird species across all major flyways have undergone population declines over the past 30 years (Kirby *et al*., 2008). There is increasing evidence of regional-scale declines in migrant birds: more Nearctic–Neotropical migrants have declined than increased in North America since the 1980s, and more Palearctic–Afrotropical migrants breeding in Europe declined than increased during 1970–2000. Regional assessments show that 51% of migratory raptors species in the African–Eurasian region and 33% of species in Central, South and East Asia have unfavorable conservation status. Some species appear to be particularly affected by declines in habitat extent and condition in non-breeding areas, notably in arid areas of tropical Africa (Kirby *et al*., 2008).

The prospect for large-bodied ungulates is no better. Mass migrations for six large-bodied ungulate species are extinct or unknown (Harris *et al*., 2009). With the exception of a few ungulates (such as Common Wildebeest *Connochaetes taurinus* and other migrants in the Serengeti Mara Ecosystem, White-eared Kob *Kobus kob* and Tiang *Damaliscus lunatus* in Sudan, and some Caribou *Rangifer tarandus* populations), the abundance of all other large-bodied migrant ungulates has declined (Harris *et al*., 2009). In the case of migratory species occurring in the marine environment, 21% are classified as threatened (i.e. categorized as Critically Endangered, Endangered or Vulnerable) with an additional 27% classified as Near Threatened or Data Deficient (Lascelles *et al*., 2014). Sea turtles are the most threatened group (85%), followed by seabirds (27%), cartilaginous fish (26%), marine mammals (15%) and bony fish (11%). Migratory species in marine ecosystems may be even more affected by climate change impacts than terrestrial species (Robinson *et al*., 2009). Highly migratory and straddling marine fishes (i.e., fish species that move through or exist in more than one exclusive economic zone) are further governed by the United Nations Fish Stocks Agreement (UNFSA), which has been in force since 2001. The objective of UNFSA is to "ensure the long-term conservation and sustainable use of straddling fish stocks and highly migratory fish stocks" (UNFSA, 2018). A recent assessment of global progress towards implementing this agreement concluded that the overall status of migratory fish stocks and straddling fish stocks had not improved since the 2006 Review Conference (Baez *et al*., 2016). Moreover, since 2010, there has been a decline in the overall status of highly migratory fish stocks and straddling stocks, and 60% of shark species are considered to be potentially overexploited or depleted (Baez *et al*., 2016).

There is little information to assess progress towards enhancing the benefits to all from the favourable conservation status of migratory species (Goal 4). Some progress has been made towards enhancing implementation through participatory planning, knowledge management and capacity-building (Goal 5). CMS Strategic Plan 2006–2011 and the Bali Strategic Plan for Technology Support and Capacity-Building provide the framework for capacity-building (CMS, 2018)**.** The Convention promotes a bottom-up and participatory approach in identifying specific objectives, strategies and activities for implementation by governments, NGOs and other stakeholders. Collaboration with NGOs to facilitate implementation and capacity-building has increased over the years, enabling cost-sharing, especially in developing and emerging economies (Prideaux, 2015), despite some NGO relationships with CMS instruments tending to be *ad hoc*, with some key discussions closed to them (Prideaux, 2014). National Biodiversity Strategy and Action Plans (NBSAPs) often fail to consider adequately the needs of migratory species which are typically not endemic or may not comprise a significant component of the local biodiversity (CMS, 2017).

3.4.2 The Convention on International Trade in Endangered Species of Wild Fauna and Flora

In force since 1975, CITES aims to ensure that international trade in specimens of wild animals and plants does not threaten their survival (CITES, 2017). The primary policy tool of CITES is the regulation of trade to avoid utilization incompatible with species' survival (Appendix II listed species) and the prohibition of trade for commercial purposes on all species listed in Appendix I (e.g., leopard *Panthera pardus*, sea turtles, bowhead whale *Balaena mysticetus*, and the monkey-puzzle tree *Araucaria araucana*). The Convention contains a number of exceptions to this general prohibition, however (CITES, 2017). It controls international trade of selected species through a licensing system that requires authorization of all import, export or re-export of all species covered. CITES presently exercises responsibility over almost 35,600 species of flora and fauna (CITES, 2017). Only 3% of these are under Appendix I. CITES has 183 Parties, which have adopted three goals outlined in the Convention's Strategic Vision (2008–2020) (CITES, 2017). The goals address compliance with, and implementation and enforcement of, the Convention (Goal 1), securing financial resources for Convention implementation and operationalization (Goal 2), and ensuring coherence and support between CITES and other multilateral agreements such as the CBD, CMS and relevant SDGs (Goal 3).

Trade in wildlife is increasing: on average, over 100 million individuals were traded annually during 2005–2014 compared with a mean of 9 million per year during 1975–1985 (Harfoot *et al*., 2018). Overall, trade seems to have shifted towards captive-bred rather than wild-sourced individuals for many (but not all) taxa (Harfoot *et al*., 2018).

Implementation compliance and enforcement of CITES is improving, but slowly, (Nowell, 2012) and trade bans are possibly worsening the situation for some species (Conrad, 2012; Santos *et al*., 2011), so progress towards Goal 1 has been moderate. Controls and bans on trade have been successful in helping to stabilize populations of certain species (Conrad, 2012; Gehring & Ruffing, 2008) such as the endangered Giant Otter *Pteronura brasiliensis* (Uscamaita & Bodmer, 2009), and spotted cats and crocodilians (Ginsberg, 2002), with some taxa showing modest population recoveries (e.g., Citron-crested Cockatoo *Cacatua sulphurea citrinocristata*; Cahill *et al*., 2006). However, unsustainable levels of wildlife trade, some of which is legal and international, continue to pose major threats to global biodiversity (Joppa *et al*., 2016; Santos *et al*., 2011). The conservation status of some species, such as Lear's Macaw *Anodorhynchus leari* and Imperial *Amazona imperialis* has improved (toward less threatened categories of the IUCN Red List) as a consequence of control of trapping and trade, including through CITES regulations, but many more species have deteriorated in status toward more threatened categories owing to unsustainable harvests driven in part by international trade (Butchart, 2008; Di Marco *et al*., 2014; Hoffmann *et al*., 2010). In some cases, bans on legal trade drive increases in illegal trade, further threatening species already at risk (Di Minin *et al*., 2016; Fischer, 2010; Rivalan *et al*., 2007). Globalization and the interlinks between organized crime, terror organizations, social conflict and illegal wildlife trade also play a key role, particularly in the recent precipitous decline of elephant and rhino species in Africa and Asia (Brashares *et al*., 2014; Sollund, 2016; Wasser *et al*., 2009; but see UNODC, 2016).

Violations of the agreement are widespread (e.g., Dongol *et al*., 2012), while trade quotas typically do not consider population dynamics and are not based on population modelling (Smith *et al.,* 2011) despite evidence that such approaches are critical for many of the species impacted by international trade (e.g., Balme *et al*., 2012; Valle *et al*., 2018). The introduction of stricter legislation, wildlife trade controls and penalties in a number of countries led to improvements in compliance during 2010–2012 (Nowell, 2012). Nevertheless, major prosecutions for wildlife crime are still rare, and overall, enforcement has lagged behind compliance, despite examples of national scale bans combined with CITES restrictions decreasing unsustainable wildlife trade (Santos *et al*., 2011). Biennial reporting was virtually moribund (Reeve, 2006) and has subsequently been replaced with the requirement for an Implementation Report covering the three-year cycles between CITES Conferences of the Parties (CITES 2018a). CITES also requires Parties to submit annual trade reports and annual illegal trade reports (CITES 2018b). Non-compliance on annual reporting of trade and illegal trade is common, however, limiting the reliability of conclusions drawn from trade statistics generated from such reports (Challender *et al*., 2015b; Foster *et al*., 2016; Phelps, 2010; Underwood *et al*., 2013).

Financial and other resources for the operation and implementation of CITES have been insufficient and are declining, meaning that we are moving away from achieving Goal 2**.** Funding remains a principal limitation to the effectiveness of CITES, especially for on-the-ground execution of mandates and for proposed enhancements (Phelps *et al*., 2010). The core administrative costs of the Secretariat, the Conference of the Parties and various committees are financed from the CITES Trust Fund which is replenished from contributions from the Parties to the Convention (CITES, 2017). Its annual budget of US$6 million is shrinking in real terms, even though Parties agreed to an increase of 0.24% in 2016. As of 31 July 2017, contributing Parties have failed to pay a total of nearly USD 850,000 for 2016 and prior years that they owe to the Trust Fund (CITES, 2017). As a 'pre-Rio' Convention, CITES cannot directly access the Global Environment Facility (Reeve, 2006). Nevertheless, during the period 1 January 2016 to 31 July 2017, CITES received USD 14.3 million in voluntary contributions to its Trust Fund. Lack of funding is one of the reasons that Parties are reluctant to establish a dedicated compliance or implementation committee (Nowell, 2012).

CITES and other multilateral instruments and processes are generally coherent and mutually supportive, meaning that there is good progress towards Goal 3**.** CITES actively engages with allied biodiversity MEAs, most significantly with the Ramsar Convention, WHC, CMS, CBD, and ITPGRFA (with which it cooperates under a body called the 'Liaison Group of Biodiversity-related Conventions' to explore opportunities for synergistic activities and increased coordination, and to exchange information; CITES, 2018c; Couzens, 2013; Yeater, 2013). Given its focus on international trade, MEA counterparts tend to refer to CITES on issues of trade and transportation permits, while the CMS has advocated close engagement with CITES and encouraged application of the lessons learned through CITES implementation (Caddell, 2013a). Although there is high level of inter-treaty cooperation (Caddell, 2012, 2013b), opportunities for enhancing synergies remain untapped (Ministry of the Environment of Finland 2010), e.g., in relation to taxonomy and reporting (Phelps *et al*., 2010). One multilateral process in which alignment with

CITES has been challenging is the International Whaling Convention, with which there has been disagreement on the hierarchical arrangement between the two regimes (Caddell, 2012, 2013b).

3.4.3 The Ramsar Convention on Wetlands

The Ramsar Convention addresses the conservation and wise use of wetlands and has 170 Parties. The four Goals of the Convention's 4th Strategic Plan (2016–2024) relate to addressing the drivers of wetlands loss and degradation (Goal 1), the effective conservation and management of the Ramsar Site network (Goal 2), wise use of all wetlands (Goal 3), and enhanced implementation of the Convention (Goal 4). Wetland loss is continuing because of poor progress in addressing the drivers of wetland loss, meaning we are moving away from achieving Goal 1. The long-term loss of natural wetlands was 54–57% since 18th century, while during the 20th and early 21st centuries the rate of loss significantly increased with a loss of 64–71% of wetlands since 1900 AD, based on a subset of sites with available data (Davidson, 2014). Although the rate of wetland lost slowed down in North America and Europe since 1980s (Davidson, 2014), 4.8% of marshes and bogs have been lost in Europe during 1990–2006 (EEA, 2015, p 18), and 80,000 acres of wetlands were lost annually during 2004–2009 in coastal watersheds in the conterminous United States (Dahl & Stedman, 2013). The rates of wetland loss remain high in Asia (Russi *et al*., 2012, p. 19–20) with, for example, an average annual loss of 1.6% of the area of wetlands in Northeast and South-East Asia (Gopal, 2013; UNEP, 2016b, p.65), 65% loss of intertidal wetlands in the Yellow Sea over the past 50 years (Murray *et al*., 2014), and loss of 51% of coastal wetlands in China, 40% in the Republic of Korea and >70% in Singapore during 1955–2005 (MacKinnon *et al*., 2012, p.1). There is limited information on wetland loss in Africa, Latin America and the Caribbean and Oceania (Davidson, 2014). The Red List Index for wetland birds, mammals and amphibians, plus corals, is continuing to decline, indicating that overall, these species are moving towards extinction (Ramsar Convention, 2018).

Wetland benefits feature in some national/local policy strategies and plans in key sectors, for example the US Agricultural Act of 2014 has funding schemes for wetland conservation (USDA, 2017) while the EU Water Framework Directive (2000) features wetlands in integrated river basin management plans to improve water quality. However, there are large gaps; for example, many wetlands in India are under anthropogenic pressures because wetlands barely figure in water resource management and development plans (Bassi, 2014), while the absence of wetland considerations in local land-use planning is the main driver for wetland degradation in the Mediterranean (Mediterranean Wetlands Observatory, 2012, p.44). Finlayson (2012) found that national-level implementation of the Ramsar Convention is, overall, inadequate. Wetlands in almost all regions continue to be degraded due to anthropogenic factors such as land claim for agriculture (e.g., in 1990–2006, 35% of wetlands loss in the EU was to agriculture; EEA, 2015, p.18; Murray *et al*., 2014; Russi *et al*., 2012), urbanization (Hettiarachchi *et al*., 2015) and pollution (Gopal, 2013; Junk *et al*., 2013; Ramsar Convention, 2018), although there are exceptions: the EU made significant progress in reducing nutrient levels in lakes and rivers between 1992 and 2007 by improving wastewater treatment and reducing agricultural inputs (EEA, 2015, p.70). Ramsar COP 12 National Reports show that in many countries some parts of public and private sectors are applying guidelines for the wise use of water and wetlands; however, there is no evidence to access the scale and effectiveness of this.

Invasive alien species threaten native biodiversity (Lodge *et al*., 2006), with wetlands being particularly susceptible to invasions (Zedler & Kercher, 2004). In Europe, the cumulative number of alien species in freshwater, marine and estuarine ecosystems has been constantly increasing since the 1900s. The trend is slowing down for freshwater species, but not for alien marine and estuarine species (EEA, 2010). In 2018, 40% of Ramsar Parties had developed a comprehensive national inventory of invasive alien species impacting wetlands, but only 26% had established national policies or guidance on control or management of invasive alien species impacting wetlands (Ramsar Convention, 2018). Information about wetland invasive alien species is increasingly accessible through the Global Invasive Species Database (http://www.iucngisd.org/gisd/).

Parties do not appear to be on track to achieve effective conservation and management of the Ramsar site network (Goal 2). Only c. 11% of inland wetlands are designated as national protected areas and/or Ramsar Sites, ranging from 20% in Central and 18% in South America to only 8% in Asia (Reis *et al*., 2017). While 2,314 Wetlands of International Importance covering 245.6 million ha had been designated Ramsar Sites as of August 2018, ecological representation remains low. Only 24% of 3,359 wetland Important Bird and Biodiversity Areas (IBAs) that qualify as Ramsar Sites had been designated under the convention by March 2015, representing 14% of the area of all qualifying sites. Coverage is highest in Europe and Africa (with at least 30% of qualifying IBAs completely or partially covered) and lowest in Asia (just 12% completely or partially covered); results for the Americas and the Pacific are currently unavailable. The percentage of qualifying IBAs completely or partially covered by Ramsar Sites has increased from 16% in 2000 to 24% in 2015 (BirdLife International, 2015). The rate of designation of Ramsar Sites has slowed considerably in the 2010s, and only

41% of Parties have established a strategy and priorities for future Ramsar Site designation (Ramsar Convention, 2018). Only slightly more than half of all Ramsar Sites have management plans that are being actively implemented (Ramsar Convention, 2018).

Progress towards wise use of all wetlands (Goal 3) has been poor. Wetland inventories are missing, incomplete or out of date in many countries (Junk *et al*., 2013), although the recent publication of a global wetland layer based on remote sensing (Pekel *et al*., 2016) may help to address this issue. Based on 140 National Reports (2018), 44% of Contracting Parties have completed National Wetlands Inventories and 29% are in progress. The proportion of Parties having completed inventories is highest in North America (67%) and Europe (62%) and lowest in Asia (30%). In 2015, 37% of Parties to the Ramsar Convention reported that they have removed perverse incentives that discourage the conservation and wise use of wetlands, while 51% reported that actions had been taken to implement positive incentives that encourage the conservation and wise use of wetlands (Ramsar Convention, 2018). By 2018, 73 Parties had established a National Wetland Policy or equivalent, and 18 additional countries have elements of such a policy in place (Ramsar Convention, 2018). Integrated resource management at the scale of river basins and coastal zones is often insufficient.

While traditional knowledge, innovations and practices of IPLCs are sometimes integrated into implementation of the Convention, this does not happen universally, despite the fact that engaging local actors in rule development typically leads to greater consensus and more effective multilateral implementation (Mauerhofer *et al*., 2015). Wetland functions, services and benefits are widely demonstrated, documented and disseminated (Ghermandi *et al*., 2010; Ramsar Convention, 2018). While some efforts are underway to restore degraded wetlands (e.g., Cui *et al*., 2009; Zhao *et al*., 2016b,), climate change is likely to exacerbate the pressures on wetlands (Finlayson *et al*., 2017; Gopal, 2013; Junk *et al*., 2013).

Implementation of the Ramsar Convention is being strengthened, but slowly (Goal 4). Scientific and technical guidance on relevant topics are increasingly available and used by policy makers and practitioners (e.g., Ramsar guidance shaped the governance of urban wetlands in Colombo, Sri Lanka; Hettiarachchi *et al*., 2015). The Ramsar Convention's Programme on communication, capacity-building, education, participation and awareness promotes World Wetland Day to mainstream wise use of wetlands. To assist in implementing the Convention, 19 Ramsar Regional Initiatives, including networks of regional cooperation such as the Niger River Basin Network and the West African Coastal Zone Wetlands Network, have been developed.

3.4.4 United Nations Convention to Combat Desertification (UNCCD)

The UNCCD has a strategic plan for 2008–2018 which sets four long-term strategic goals and five short- and medium-term operational objectives (UNCCD, 2007). The goals aim to: improve living conditions of the communities (Goal 1) and the ecosystems (Goal 2) affected by land degradation and desertification; generate global benefits for biodiversity conservation and climate change mitigation (Goal 3); and mobilize resources and build partnerships for implementation of the Convention (Goal 4).

There has been poor progress towards improving the living conditions of affected populations (Goal 1). Desertification and land degradation are roughly estimated to affect over 1.5 billion people whose livelihoods and well-being are dependent on dryland areas and agriculture (Amiraslani & Dragovich, 2011; Bai *et al*., 2008; Sanz *et al*., 2017 p.29,). Adverse effects of land degradation have most impact on the poor and vulnerable social groups (IPBES, 2018). Globally, 74% of the poor (42% of the very poor and 32% of the moderately poor) are directly affected by land degradation (Sanz *et al*., 2017). About 20% of irrigated land (45 million hectares) is moderately or severely salinized (Rengasamy, 2006), including the Indo-Gangetic Basin in India (Gupta & Abrol, 2000), Aral Sea Basin of Central Asia (Cai *et al*., 2003), and the Murray-Darling Basin in Australia (Rengasamy, 2006). Desertification undermines affected people's livelihoods and contributes to increased levels of poverty and rural-urban migration (Amiraslani, 2011; Bates, 2002; Verstraete, 2009). Although migration is often caused by a mix of social, economic, political and environmental drivers (Warner *et al*., 2010), 'environmental migrants' outnumber traditional socio-political refugees in sub-Saharan Africa (Myers, 2002). Desertification may displace globally 50 million people in the next 10 years (Sanz *et al*., 2017). Since the mid-20th century, there has been increasing aridification of Africa, East and Southern Asia, Eastern Australia, and Southern Europe (Dai, 2011; Sheffield *et al*., 2009). Under a 'business-as-usual' scenario, up to 50% of the earth's surface may be in drought at the end of the 21st (Burke *et al*., 2006). Increasing droughts may further jeopardize the livelihoods and well-being of communities dependent on agriculture (Morton, 2007).

There seems to be a moderate progress towards improving the condition of affected ecosystems (Goal 2). There has been 'some progress' towards UNCCD targets related to deforestation, but 'little or no progress' towards those related to desertification and drought (UNEP, 2012). While some subtropical deserts (e.g., the Sahara, Arabian, Kalahari, Gobi and Great Sandy Desert) are expanding (Zeng & Yoon, 2009), some arid territories such as the Sahel, the Mediterranean basin, Southern Africa are currently 'greening up' and are not expanding (Hellden & Tottrup, 2008). Estimates of the global area of degraded land range between 1 and 6 billion ha (Gibbs and Salmon, 2015). Of the c. 24% of global land area that is degrading, 23% is broadleaved forest, 19% is needle-leaved forest, and 20–25% is rangeland (Bai *et al*., 2008). One of the drivers is land conversion for agricultural expansion (Lambin & Meyfroidt, 2011), especially in the tropical forest regions (Gibbs *et al*., 2010; Keenan *et al*., 2015). Desertification also contributes to the emission and long-range transport of fine mineral dust (D'Odorico *et al*., 2013), which may adversely affect ecosystems ranging from lowlands to mountain glaciers (Indoitu *et al*., 2015).

We appear to be making moderate progress in generating global benefits for the conservation and sustainable use of biodiversity and the mitigation of climate change through implementation of the convention (Goal 3). Land degradation, affecting about 25% of global land area (Bai *et al*., 2008), influences in a complex way the magnitude and direction of climate impacts on agricultural land and biodiversity (Webb *et al*., 2017). Practices and technologies that mitigate land degradation, climate change adaptation and mitigation often positively affect biodiversity (Sanz *et al*., 2017, p. 81). Climate change is likely to affect agricultural yields and threaten future global food security (World Bank, 2008, p. 100) and reduce communities' adaptability and resilience towards climate change (Neely *et al*., 2009). Net greenhouse gas emissions from land-use changes amounted to approximately 10–12% of total emissions around the year 2005 (Sanz *et al*., 2017, p. 35). Although CO2 emissions from net forest conversion in 2011–2015 decreased significantly since 2001–2010 period, the share of CO2 emissions from forest degradation increased (Federici *et al*., 2015). Global emissions from land use, land use change and forestry decreased from 1.54±1.06 $GtCO_2e\ yr^{-1}$ in 1990 to 0.01±0.86 $GtCO_2e\ yr^{-1}$ in 2010, and future net emissions by 2030 range from an increase of 1.94 ± 1.53 $GtCO_2e$ yr−1 to a decrease of −1.14±0.48 $GtCO_2e\ yr^{-1}$ under different policy scenarios (Grassi *et al*., 2017). Reducing agriculture-driven deforestation and forest-sparing interventions could reduce 1-1.3 $GtCO_2e\ yr^{-1}$ from the agriculture sector (Carter *et al*., 2015). Most countries (89%) have included agriculture and/or land use, land-use change and forestry (LULUCF) in emission reduction targets in their Intended Nationally Determined Contributions (Sanz *et al*., 2017, p.37).

Good progress has been made in mobilizing resources to support implementation of the Convention through building effective partnerships between national and international actors (Goal 4). UNCCD has committed to harmonize its strategies with the SDGs and direct its activities to meet SDG 15.3 (to combat desertification and restore degraded land and soil… and strive to achieve a land degradation-neutral world). With support from the convention, 102 countries agreed in 2016 to set voluntary Land Degradation Neutrality targets. The formal agreement of the definition of Land Degradation Neutrality in 2015 (UNCCD, 2015) was followed by the development of a Scientific Conceptual Framework for Land Degradation Neutrality, which takes into account quantitative and qualitative data and emphasizes stakeholder participation (Akhtar-Schuster *et al*. 2017; Cowie *et al*., 2018; Orr *et al*., 2017).

UNCCD has developed a monitoring and assessment framework, which takes into account quantitative and qualitative data and emphasizes stakeholder participation (Akhtar-Schuster *et al*., 2017). There are some challenges in operationalizing indicators against these targets (Chasek *et al*., 2015; Dooley & Wunder, 2015; Sietz *et al*., 2017), a lack of baseline data for assessing progress (Grainger, 2015) and no uniform criteria and standard methodology to assess land degradation and the effectiveness of restoration measures; nevertheless, progress towards setting Land Degradation Neutrality targets appears to be significant.

3.4.5 The Convention concerning the Protection of the World Cultural and Natural Heritage

The WHC was adopted by the General Conference of the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 1972, and came into force in December 1975. The Convention seeks to encourage the identification and conservation of natural and cultural heritage of 'Outstanding Universal Value', which is defined as 'cultural and/or natural significance which is so exceptional as to transcend national boundaries and to be of common importance for present and future generations of all humanity' (UNESCO WHC, 2016). The Convention requires its 193 Parties to identify and protect relevant sites (UNESCO WHC, 2017). The WHC is the most universal international legal instrument for global protection of cultural and natural heritage.

World Heritage Sites are landmarks or areas of outstanding universal value that have been officially recognized by UNESCO, following decisions from the intergovernmental World Heritage Committee. Signatories have to conserve both world heritage and national heritage in their countries. As of April 2018, there are 1,092 sites on the World Heritage List, of which 209 sites are classified as 'natural' heritage, 845 as 'cultural' heritage and 38 as 'mixed' heritage (i.e., natural and cultural) (UNESCO, 2018). Natural heritage sites include natural features, geological and physiographical formations, and natural areas with aesthetical, scientific and conservation value. Parties are encouraged to integrate cultural and natural heritage protection into regional planning programmes, undertake relevant conservation research, and enhance the function of heritage in people's lives. The World

Heritage Committee may inscribe a property on the 'List of World Heritage in Danger'. At present, 16 of the 54 sites on this list are natural sites (UNESCO, 2018). Annual reviews are required of the state of conservation of properties on the List.

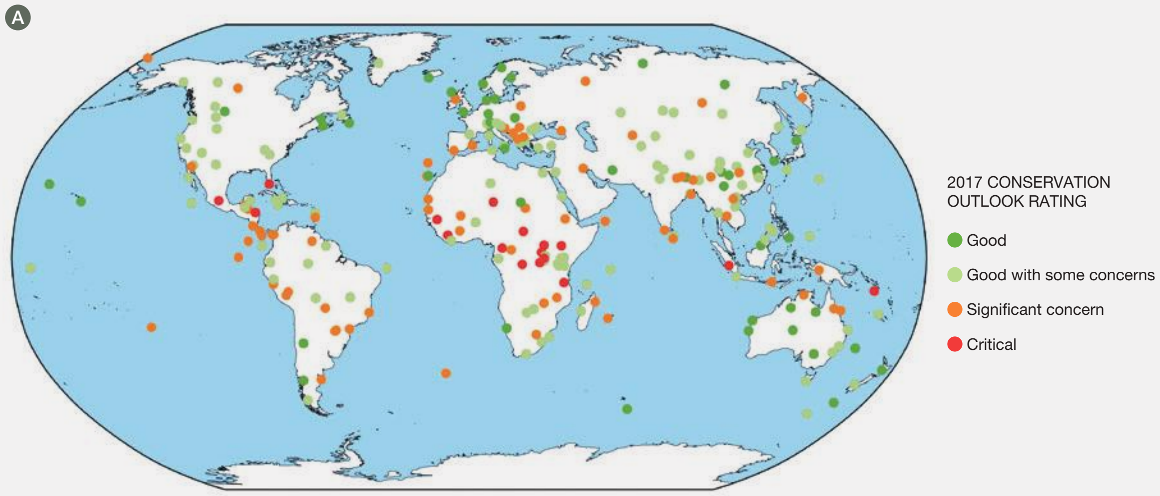
In 1994, the World Heritage Committee launched a Global Strategy for a Representative, Balanced and Credible World Heritage List to ensure that it reflects the world's cultural and natural diversity of outstanding universal value. In 2002, at its 26th Session of the Committee, the Budapest Declaration on World Heritage was adopted, setting out four main objectives of the Convention; a fifth was added in 2007. In November 2017, UNESCO published the World Heritage Outlook 2, which assessed the conservation status of 241 natural and mixed sites.

Good progress has been made to strengthen the credibility of the World Heritage List as a representative and geographically balanced testimony of cultural and natural properties of outstanding universal value (Objective 1). The number of States (i.e. Parties) to the WHC has risen from 139 to 167 in the last 20 years, with the number of sites listed growing from 33 to 1,092 (UNESCO, 2018). The list of sites is often accused of being highly biased, with Europe and North America having 47% of all sites (23% of all natural sites) while sub-Saharan Africa and the Arabian countries, for example, have 9% and 8% of all sites, respectively (Frey *et al*., 2013; Bertacchini and Saccone, 2012). In an effort to improve geographic representativeness, the WHS Secretariat has encouraged more countries to submit Tentative Lists for consideration (183 States have done this so far; UNESCO, 2018). Evaluations of the representativeness of World Heritage Sites indicate that they provide highly uneven biodiversity coverage, and underrepresent tropical and subtropical coniferous forests, temperate grasslands, Mediterranean forests, and tropical and subtropical dry forests (Anthamatten & Hazen, 2007; Bertzky, *et al*., 2013; Brooks *et al*., 2009). These biomes, however, are also poorly represented by protected areas more generally (Anthamatten & Hazen, 2007). Moreover, some Parties do not have any inscribed sites, even though they may possess sites likely to fulfil the selection criterion of 'outstanding universal value' (Frey *et al*., 2013). The dominance of the national over the international interest in World Heritage Site selection has also been noted (Frey *et al*., 2013).

Poor progress has been made in ensuring the effective conservation of World Heritage properties, particularly natural sites (Objective 2). Natural World Heritage sites are facing a wide range of threats, particularly invasive species, tourism, commercial hunting, fishing, dams and logging (Osipova *et al*., 2014, 2017). The two most significant current threats to natural World Heritage are invasive species and climate change **(Figure 3.14)**. Tourism impacts, legal and illegal fishing and hunting, fires, water pollution and dams are among the top threats. Between 2014 and 2017, the number of sites for which climate change was assessed as high or very high threat almost doubled, while the threat of fires increased by 33% (from 27 to 36 sites) (Osipova *et al*., 2017). Regional differences in current threat assessments exist. The highest number of sites where climate change was assessed as a high or very high current threat were in Oceania and Mesoamerica and the Caribbean. Oceania and North America have the most sites where invasive species are a high or very high threat. Europe and Asia have the most sites where tourism is a high or very high threat.

Only about half of the natural sites on the World Heritage List are regularly monitored through the main monitoring mechanisms of the Convention (Osipova *et al*., 2014). For those regions where Key Biodiversity Areas have been comprehensively assessed, all natural and mixed World Heritage sites have been found to qualify as Key Biodiversity Areas (Foster *et al*., 2010). For almost two thirds of all sites (64%) the conservation outlook is either good or good with some concerns, for 29% of sites the outlook is of significant concern, and for 7% it is critical (Osipova *et al*., 2017). Some World Heritage sites are additionally recognized as fulfilling the criteria for Outstanding Universal Value, defined as having "cultural and/or natural significance which is so exceptional as to transcend national boundaries and to be of common importance for present and future generations of all humanity" (UNESCO, 2016). For 70% of World Heritage sites, the values for which they were listed are either in a good state or of low concern, whereas for 27% and in 5% of sites the current state is of high concern or critical, respectively **(Figure 3.14)**. In 2014, the values associated with geoheritage (criterion viii) were in the best condition, with 94% of cases assessed as either good or of low concern. The values associated with biodiversity have tended to be of higher concern (Osipova *et al*., 2014, 2017).

Osipova *et al*. (2017) assessed 14 criteria for site protection and management and concluded that "only 48% of sites have overall effective or highly effective protection and management and in 12% of sites protection and management are of serious concern". Protection and management effectiveness decreased between 2014 and 2017, with the most effective criterion being research while sustainable finance was the criterion of highest concern. Good progress is being made in promoting the development of effective capacity-building measures, including for preparing site nominations and implementing the Convention (Objective 3). World Heritage programmes addressing this objective include resource manuals to help Parties nominate sites, to manage natural and cultural values within them, and to manage of disaster risks, and capacity-building. However, there is no independent



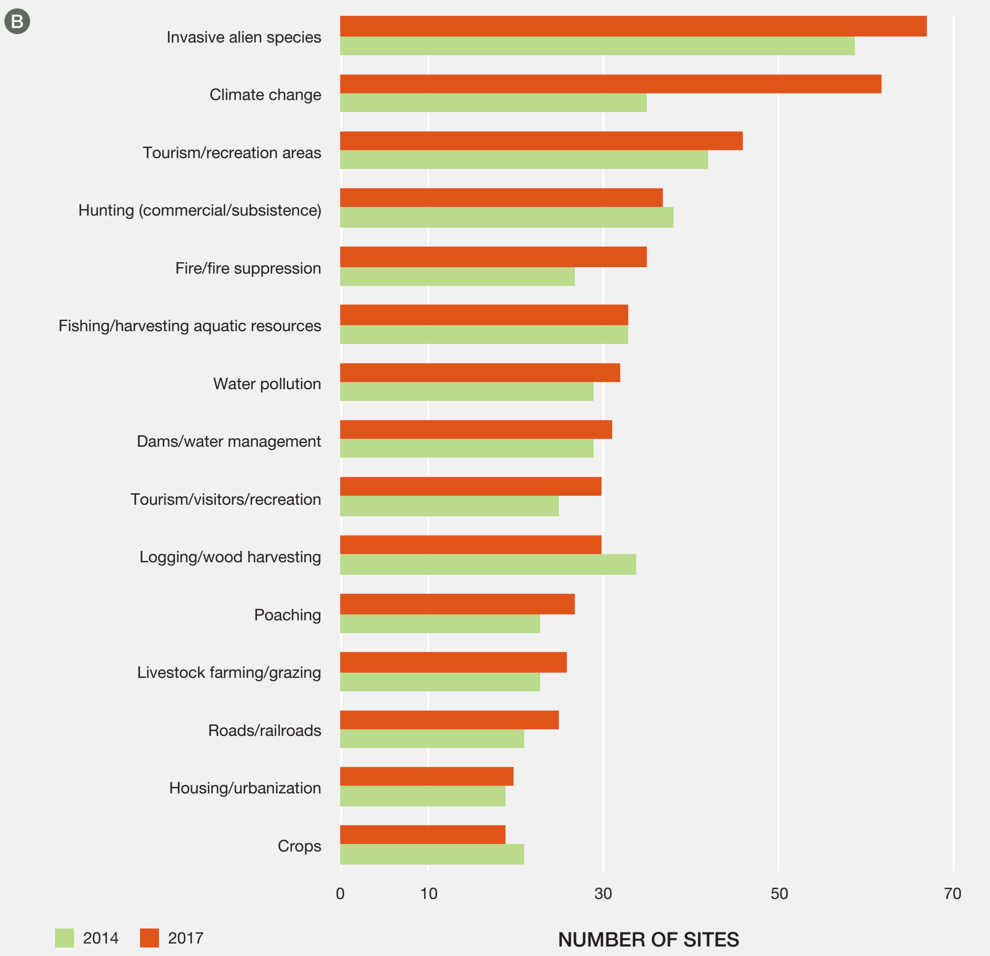


Figure 3 14 **A Conservation Outlook rating of 241 natural World Heritage sites, and B threats to natural World Heritage sites assessed as high or very high in 2014 and 2017.**

Source: Osipova *et al.*,(2017).

information on the effectiveness of these measures in building capacity.

Recent improved communication efforts have increased public awareness, involvement and support for World Heritage, indicating progress towards Objective 4, but information to assess this robustly is lacking. Awareness is likely to have been raised through the publication of the World Heritage Paper Series (launched in 2002), the dissemination of the quarterly World Heritage Review and World Heritage Newsletter, through the World Heritage Volunteers Initiative, the World Heritage Education Programme and the recent publication of the World Heritage Outlook 2.

The role of communities in the implementation of the World Heritage Convention is likely to have been enhanced, but at an insufficient rate (Objective 5). Programmes such as the World Heritage Volunteers Initiative and World Heritage Education Programme are likely to have increased community involvement, and there are a number of examples of sustainable development at World Heritage Sites being achieved through the involvement of local communities and the integration of multiple values and traditional and local ecological knowledge (Galla, 2012). In terms of relationships with local people, a criterion that was assessed in Outlook 2, it was considered highly effective in 35 sites and of serious concern for 22 sites of the 241 natural WHS (**Figure 3.14**; Osipova *et al*., 2017).

3.4.6 The International Plant Protection Convention

The IPPC has set four Strategic Goals for the period 2012–2019: A) to protect sustainable agriculture and enhance global food security through the prevention of pest spread; B) to protect the environment, forests and biodiversity from plant pests; C) to facilitate economic and trade development through the promotion of harmonized scientifically based phytosanitary measures; and D) to develop phytosanitary capacity for members to accomplish a), b) and c). IPPC's Strategic Goals contribute to the Strategic Objectives of the Food and Agriculture Organization of the United Nations, as well as to Sustainable Development Goals 8, 13, 15 and 17 and Aichi Target 9. Strategic Goal B is the one most closely related to conservation of biodiversity, while Goals A, C and D are more focused on agriculture and food security.

There is poor progress towards protecting sustainable agriculture and enhancing global food security through the prevention of pest spread (Goal A). Crop losses to pests have not significantly decreased during the last 40 years (Oerke, 2006). Analysis of the distribution of pests (arthropods, gastropods and nematodes), pathogens (fungi, oomycetes, protozoa, bacteria and viruses) and crops shows that more than one tenth of all pests have reached more than half the countries in which the crops they affect are grown. By the middle of the 21st century, these crop producing areas are likely to be fully saturated with pests (Bebber *et al*., 2014). Fungi and oomycetes are the most widespread and most rapidly spreading crop pests and make up the largest fraction of the 50 most rapidly spreading pests. Although some pests have global distributions, the majority of pest assemblages remain strongly regionalized, with their distributions determined by the distributions of their hosts (Bebber *et al*., 2014). Human activities remain the main factor facilitating spread of pests, although climate change may play a growing role in future. An average poleward shift of 2.7 ± 0.8 km yr−1 since 1960 has been observed for hundreds of pests and pathogens, with significant variation in trends among taxonomic groups (Bebber *et al*., 2013).

Global agricultural intensification is continuing in order to meet the increasing demand for food (Phalan *et al*., 2011; Tilman *et al*., 2011), but the associated landscape simplification negatively affects natural pest control. Growing agricultural expansion has a negative effect on biodiversity (Kehoe *et al*., 2017). Homogeneous landscapes dominated by cultivated land have 46% lower pest control levels than more complex landscapes. Conserving and restoring semi-natural habitats helps to maintain and enhance pest control services provided by predatory arthropods to agriculture (Rusch *et al*., 2016), and this also benefits biodiversity more broadly.

There is poor progress towards protecting the environment, forests and biodiversity from plant pests (Goal B). Biosecurity measures are critical for future food security (Cook *et al*., 2011), but pesticides remain the predominant measure for pest control in agriculture, with a >750% increase in pesticide production between 1955 and 2000 (Tilman *et al*., 2001). Broadscale and prophylactic use of some pest control measures such as insecticides may harm other organisms that are beneficial to agriculture, and in turn their ecological function, such as pollination (van der Sluijs *et al*., 2014; Whitehorn *et al*., 2012). Meta-analysis of 838 peer-reviewed studies (covering >2,500 sites in 73 countries) suggests that 52.4% (5,915 cases; 68.5% of the sites) of the 11,300 measured insecticide concentrations exceeded the accepted regulatory threshold levels for either surface water or sediments (Stehle & Schultz, 2015). High pesticide levels negatively affect freshwater invertebrate biodiversity (Beketov *et al*., 2013). Alternatives to intensive insecticide application include using more diverse crop rotations, altering the timing of planting, tillage and irrigation, using alternative crops in infested areas, applying biological control agents, and using lower-risk insecticides (Furlan & Kreutzweiser, 2015). Non-crop habitats at landscape scale tend to increase the diversity and/or the abundance of pests' natural enemies in fields (Attwood *et al*., 2008; Langelotto & Denno, 2004), which provides more effective control of herbivorous arthropods (Letourneau *et al*., 2009).

Good progress is being made to facilitate economic and trade development through the promotion of harmonized scientifically based phytosanitary measures (Goal C). The Agreement on the Application of Sanitary and Phytosanitary Measures is an important part of the World Trade Organization's Law of Domestic Regulation of Goods. Articles 2.2. and 5.6 require that sanitary and phytosanitary measures must not be trade-restrictive, and they must be based on scientific principles and applied only to the extent necessary to protect human, animal or plant life or health (Marceau & Trachtman, 2014). Sanitary and phytosanitary measures tend to restrict trade by increasing the costs for exporters of entering the market (Crivelli & Gröschl, 2015), especially for middle- and low-income exporting countries (Swinnen & Vandermoortele, 2011; Yue *et al*., 2010). Increasing stringency of such measures in developed countries has a substantial negative effect on exported volumes from developing countries (Melo *et al*., 2014). At the same time, these measures increase consumer confidence in product safety and positively affect trade of those exporters that comply with the requirements (Crivelli & Gröschl. 2015; Henson & Humphrey, 2010; Sheldon, 2012). Overall, such measures and their stringency do not tend to evolve uniformly across countries and regions (Woods *et al*., 2006) and the exporters capable of compliance tend to outcompete those which are not (Murina *et al*., 2015). Analysis of 47 fresh fruit and vegetable product imports into the USA from 89 exporting countries during 1996–2008 showed that sanitary and phytosanitary measures generally reduce trade in the early stages, but then their restrictiveness diminishes as exporters accumulate experience and reach a certain threshold (Peterson *et al*., 2013).

There has been moderate progress towards developing phytosanitary capacity for IPPC Parties to accomplish these goals (Goal D). Human-mediated pathways remain the main source of agricultural pest spread at global and regional scales (Bebber *et al*., 2013; Lopes-da-Silva *et al*., 2014). IPPC has developed the National Phytosanitary Capacity Development Strategy in 2012 as well as the Phytosanitary Capacity Evaluation tool. The latter provides a summary of a country's phytosanitary capacity at a particular time, which can be used for further strategic planning, priority setting and fundraising (IPPC, 2017).

Box 3 1 **Progress towards achieving the objectives of the United Nations Convention on the Law of the Sea (UNCLOS).**

Background on UNCLOS is given in section S3.11. Here we describe progress towards the objectives of UNCLOS Articles 61-68.

Progress in conserving fisheries stocks

Based on stock size and exploitation rates as indicators of a population's maximum sustainable yield, stocks overfished beyond biologically sustainable levels increased from 10% in 1974 to 31.4% in 2013. Of the stocks assessed in 2013, 58.1% were fully fished and only 10.5% were underfished (FAO, 2016). These assessments do not consider broader impacts such as those from by-catch, habitat and food web alteration. Since the 1950s, marine captures increased continuously until reaching a maximum of 86.4 million tonnes (mt) in 1996, but since then, captures have slowly declined, becoming relatively stable between 2003 and 2009, with slight growth to reach a new maximum in 2014 (81.5 mt), the last year fisheries catches were analyzed and reported globally (FAO, 2016). While global captures have been relatively stable, regional patterns have changed in response to local and regional changing conditions, deployment of new fishing technologies and increased fishing capacity (FAO, 2014a, 2016; Hazin *et al*., 2016; Rosenberg, 2016).

The largest marine fisheries landings are for Peruvian anchoveta, Alaska pollock, skipjack tuna, several sardine species, Atlantic herring, chub mackerel, scads, yellowfin tuna, Japanese anchovy and largehead hairtail. The trends for each of these groups or populations has been highly variable (FAO, 2016). In addition, climate change has already produced shifts in the distribution and productivity of some fisheries resources, especially those that are highly sensitive to changing oceanographic conditions (e.g., Peruvian anchoveta) (FAO, 2016; Rosenberg, 2016). Highlighting the most iconic fisheries, tuna captures reached a maximum in 2012 of 7 mt. For tuna and billfish, about half of the 41 assessed populations are under variable fishing pressures including being overfished or experiencing overfishing, or both (Restrepo *et al*., 2016; Inter-American Tropical Tuna Commission (IATTC) reports: https://www.iattc.org/StockAssessmentReports/StockAssessmentReportsENG.htm). For sharks (and other chondrichthyans), many populations are overexploited, with more than 2 mt of sharks captured per year, and some species are threatened. The shark fin market alone comprises more than 17,000 tonnes (Dulvy *et al*., 2017; Ward-Paige, 2017). Maximum global landings of sharks occurred in 2000 and have declined since then. These declines may be attributed to conservation management measures adopted by several RFMOs (e.g., prohibitions of catch for certain shark species; introduction of by-catch mitigation measures) (http://www.fao.

org/ipoa-sharks/regional-sharks-measures/en/), or to a change (and reduction) of consumption patterns in major markets including China (Vallianos *et al*., 2018). However, declines in landing have also been attributed to populations declines (Davidson *et al*., 2016).

Among invertebrates, the most valuable groups, lobster, shrimps and cephalopods (mostly squid), reached maximum levels of captures in 2014 (shrimp catches are stable around 3.5 mt and cephalopod catches exceeded 4.5 mt) (FAO, 2016). The areas where most global fisheries occur are the Northwest Pacific (27%), the Western Central Pacific (15%), the Southeast Pacific (11%) and the Northeast Atlantic (10%). About 18 countries are responsible for 76% of global captures (FAO, 2016).

In addition to the effects of captures on target species, there are also significant effects on by-catch species, ecosystems, food webs and benthic and demersal habitats (Hazin *et al*., 2016). While there has been increased awareness of these problems and efforts made to reduce by-catch and other broader ecosystem impacts of fishing, implementation of by-catch mitigation measures is variable, and there is insufficient monitoring of their success (Rosenberg, 2016).

Finally, catches in illegal, unreported and unregulated (IUU) fisheries, which have major negative effects on biodiversity, have been estimated to total 11-26 mt per year, concentrated in developing countries in particular. IUU fisheries have undermined the effectiveness of stock management measures (Gjerde *et al*., 2013). Success in reducing IUU fisheries varies across counties and regions and is highly related to governance (Agnew *et al*., 2009) and the effectiveness of law enforcement (Gjerde *et al*., 2013).

Progress in conserving other marine biodiversity

Best estimates of the proportion (with lower and upper estimates) of threatened species varies between taxonomic groups. In decreasing order these are: marine mammals 41% (28-60%); reef-building corals 33% (27-44%); sharks and rays 31% (18-59%); marine birds 20% (20-21%); marine reptiles (marine turtles, crocodiles and seasnakes) 20% (14-44%); hagfishes 20% (12-51%); mangroves 17% (16-21%); seagrasses 16% (14-26%); cone snails 8% (6-20%); selected marine bony fishes (sturgeons, tunas, billfishes, blennies, pufferfishes, angelfishes, butterflyfishes, surgeonfishes, tarpons, ladyfishes, groupers, wrasses, seabreams, picarels and porgies) 7% (6-18%); lobsters <1% (0-35%) (**Figure 3.15**; IUCN, 2017). The most threatened group, marine mammals, has seen the reduction of almost all populations since pre-exploitation times, with some species becoming extinct, such as Steller's Sea Cow *Hydrodamalis gigas* and Caribbean Monk Seal *Neomonachus tropicalis* (IUCN, 2017). Banning hunting has allowed for population recovery of the humpback whale *Megaptera novaeangliae* and blue whale *Balaenoptera musculus* following controls on commercial whaling. Protecting the feeding and breeding areas has also proved to be effective in the recovery of some marine mammal populations (Rodrigues *et al*., 2014). However, marine mammals still face many anthropogenic threats mostly due to habitat alterations (e.g., pollution, coastal development, noise) and climate change (Smith *et al*., 2016). The fact that there is a significant bias towards the study of less endangered species may also hinder the ability of policymakers to develop and apply the most appropriate conservation and management practices (Jaric *et al*., 2014).

The second most threatened group, corals, are impacted by a variety of stressors including pollution, sedimentation, physical destruction, overfishing, diseases, ocean acidification, and climate change. These stressors act synergistically with natural stresses and result in significant damage (Wilkinson *et al*., 2016), in particular the loss of live coral cover. In the Caribbean, average coral cover was reduced from 34.8% in the 1970s-1980s to 16.3% in ~2000-2010 (Jackson *et al*., 2014). At present, one of the major concerns is large-scale coral bleaching, which is associated with increasingly warming waters. Bleaching events have become more frequent, severe, and extensive, hindering the capacity of corals to recover (Hughes *et al*., 2017a, 2018). For example, the Great Barrier Reef suffered a bleaching event in 2015-2016 that affected 75% of surveyed locations.

Seabirds are threatened by pressures both at sea (e.g., fishing by-catch, pollution) and on land (e.g., disturbance, hunting, and predation by invasive species), and their status has deteriorated significantly in recent decades (Croxall *et al*., 2012; Lascelles *et al*., 2016). Almost 30% of 346 seabird species are globally threatened, and nearly half are known or suspected to have population declines (Croxall *et al*., 2012). Targeted conservation actions, including eradication of invasive species such as feral cats and rats from islands with seabird breeding colonies, and other actions focused on the most important marine and terrestrial locations for seabirds (identified as Important Bird and Biodiversity Areas) have improved the status of some populations and species (Croxall *et al*., 2012). FAO plans to reduce incidental by-catch of seabirds (http://www.fao.org/fishery/ipoa-seabirds/npoa/er/en) have not yet reduced this threat to seabirds (Croxall *et al*., 2012).

Trends in other groups of marine species (e.g., plankton, benthos, fish and pelagic macro-invertebrates, marine reptiles) and habitats are mostly negative (see the World Ocean Assessment (http://www.un.org/depts/los/global_reporting/WOA_RegProcess.htm; Rice, 2016). In general, no ocean biodiversity nor ecosystem has escaped the impact of human pressures. These pressures act either directly or indirectly and vary in intensity and spread. The most stressing impacts that act on marine biodiversity and ecosystems which also have societal and economic consequences are climate change (e.g., temperature increase and acidification), overfishing and human disturbance (e.g., catches, by-catches, collisions, net entanglement, habitat destruction), input of pollutants and solid waste to the ocean (e.g., nutrients, plastics, pathogens), increase in use of ocean space and physical alteration (e.g., shipping routes, wind farms, causeways, major channels), underwater noise, and introduction of invasive alien species (Bernal *et al.*, 2016). Despite some progress in developing ecosystem-based approaches to manage human activities in the ocean, there is still a major need for assessments that integrate all environmental components across social and economic sectors for all parts of the world. To accomplish this, significant capacity development will be required (Bernal *et al.*, 2016).

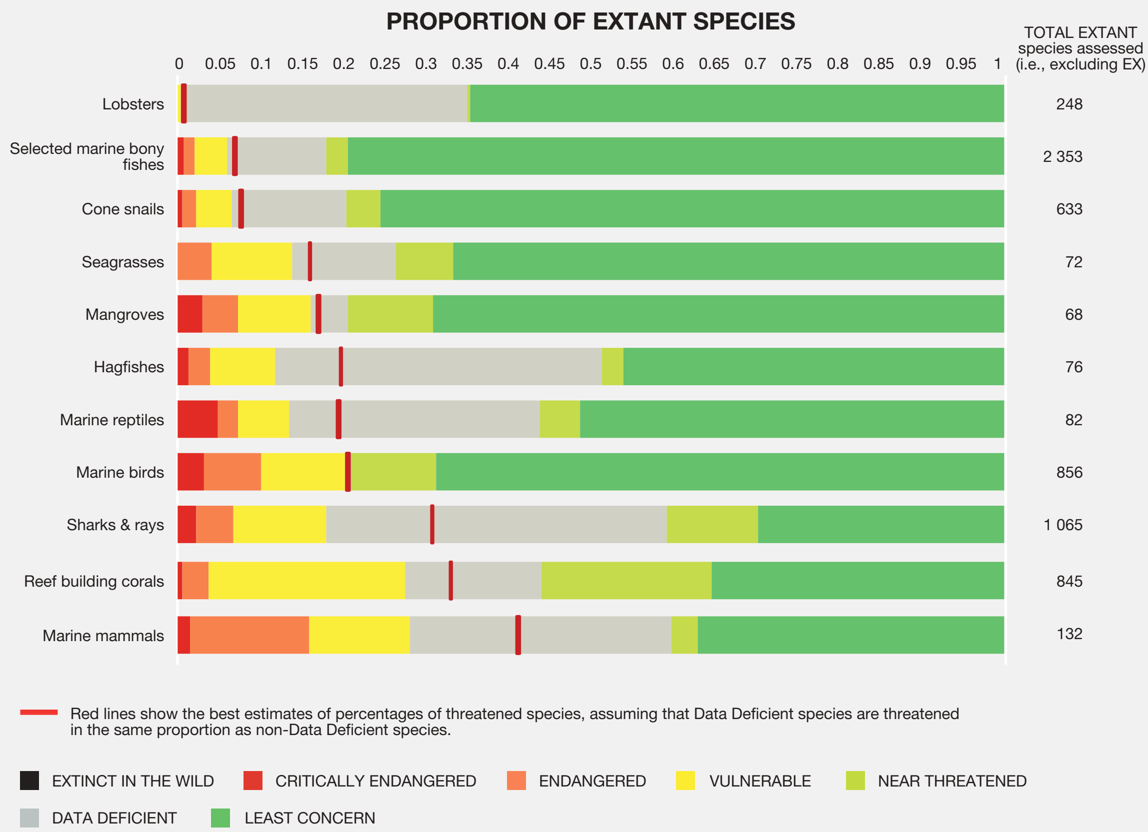


Figure 3 15 **The proportion of marine species in each category of extinction risk on the IUCN Red List.**

Groups are ordered according to the vertical red lines, which indicate the best estimate for proportion of extant species considered threatened (Critically Endangered or Vulnerable). The numbers to the right of each bar represent the total number of extant species assessed for each group. Extinct species are excluded. Source: IUCN (2017).

Protecting marine areas

For progress towards establishing marine protected areas, including description of Ecologically and Biologically Significant Areas (a process coordinated by the CBD), and the establishment of protected areas for biodiversity beyond national jurisdictions (a process managed through the United Nations General Assembly) see section 3.2. on Aichi Target 11.

Box 3 2 Progress towards achieving the objectives of polar agreements and cooperative arrangements.

The Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR)

Background on CCAMLR is given in section S3.12. Here we describe progress towards its objectives. CCAMLR has achieved considerable progress to meeting its goal of "conservation of Antarctic living resources". It is regarded as a leader in High Seas conservation (Brook, 2013) and in developing ecosystem-based fisheries management (Constable, 2011). Progress made towards achieving the goals of the Convention include: 1) the establishment and enforcement of fisheries controls, 2) the establishment Marine Protected Areas (MPAs) within the Convention area in accordance with international law (including UNCLOS), 3) the reduction of seabird mortality, 4) the establishment of the CCAMLR Ecosystem Monitoring Program (CEMP), and 5) the identification and management of vulnerable marine ecosystems (e.g., seamounts, hydrothermal vents, cold water corals and sponge fields).

With regard to fisheries, CCAMLR has implemented a series of measurements to address the impact of bottom fisheries (trawling or demersal long-lines) as well as to control illegal, unreported and unregulated (IUU) fishing. Such measures include the appointment of scientific observers under the CCAMLR Scheme of International Scientific Observation within every ship engaged in fisheries (Reid, 2011). This internationally recognized program has successfully improved the conservation of the seafloor and seabirds (Croxall, 2013) and the identification of vulnerable marine ecosystems (Reid, 2011). Such methods and encounter protocols developed for fishing vessels to identify and protect vulnerable marine ecosystems have led to calls for regulation of bottom fishing on the high seas (Reid, 2011). Bottom trawling has been banned around the Antarctic Peninsula since the early 1990s. Since then, some stocks have recovered in this area; however, neither the mackerel icefish *Champsocephalus gunnari*, one of the most abundant species before exploitation, nor the yellow notothenia *Gobionotethen gibberifrons* have yet recovered (Gutt *et al*., 2010).

With regard to the establishment of marine protected areas, CCAMLR has negotiated the establishment of important protected areas in the Southern Ocean, e.g., in the South Orkney Islands in 2010, and in the Ross Sea in 2016 (Brook, 2013; CCAMLR, 2016; UNEP-WCMC & IUCN, 2018). The marine protected area in the Ross Sea is the largest in the world, covering more than 2 million km^2 (CCAMLR, 2016). Another potential major protected area in the Weddell Sea is currently under consideration (Teschke *et al*., 2013, 2014).

Overexploitation of fisheries resources, mainly Antarctic toothfish *Dissostichus mawsoni*, Patagonian toothfish *D. eleginoides*, and mackerel icefish, along with bycatch, habitat loss, human disturbance, pollution and climate change are the major threats to marine biodiversity and ecosystems in the Southern Ocean (Alder *et al*., 2016; Griffiths, 2010). For seabirds, significant decreases in populations of species known to be caught on longline fisheries (e.g., albatrosses, Southern Giant Petrel *Macronectes giganteus* and large petrels *Procellaria* spp.) had been reported in the early 2000s (Tuck *et al*., 2003; Woehler *et al*., 2001). While populations in the north of the CCAMLR area are still at risk, the reduction of seabird mortality has been significant in fisheries regulated by CCAMLR (Ramm, 2013).

Scientific research and monitoring have been intensive in the Southern Ocean for more than a century. One of the most noteworthy of these research programs was the Census of Antarctic Marine Life (CAML), a project framed in the Census of Marine Life program. Within the CAML framework and the International Polar Year 2007-2009, 19 research voyages were coordinated with researchers from over 30 nations (Miloslavich *et al*., 2016). These expeditions significantly advanced our understanding of Southern Ocean ecosystems and biodiversity (Brandt *et al*., 2007; Broyer and Koubbi, 2014) and also helped to identify and declare new areas as vulnerable marine ecosystems (Gutt *et al*., 2010). To manage the effects of fishing in both target and associated species, the CAMLR convention also established in 1989 the Ecosystem Monitoring Program (CEMP) to allow for the detection of changes in the ecosystem components and their attribution. CAMLR goals and CEMP are supported by a very strong community of practice (e.g., the Southern Ocean Observing System; SOOS). SOOS has proposed and is currently developing a set of ecosystem Essential Ocean Variables to be measured in a sustained and coordinated manner to assess changes in Southern Ocean diversity and ecosystems and its causes (Constable *et al*., 2016).

The Conservation for the Arctic Flora and Fauna (CAFF)

Background on CAFF is given in section S3.12. Here we assess progress towards its objectives. Research and monitoring have been carried out in the Arctic for more than a century, but given the size, remoteness, habitat complexity and technical challenges, baseline inventories of species in many areas are still lacking or incomplete, especially for the marine realm (Gradinger *et al*., 2010). This knowledge gap makes it very difficult to assess Arctic biodiversity patterns and trends over time (Archambault *et al*., 2010; CAFF, 2013; Lindal Jorgensen *et al*., 2016). However, with the Circumpolar Biodiversity Monitoring Program and the State of the Arctic Biodiversity reports, gaps and available data are being identified for the Arctic Focal Ecosystem Components (CAFF, 2017). The Arctic has undergone dramatic changes since the Holocene, driven mostly by climate fluctuations which have impoverished its biodiversity. At present, climate change is the most important driver of environmental change in terrestrial, freshwater and marine ecosystems, including the thinning of the ice pack (CAFF, 2017; Ims and Ehrich, 2013; Michel, 2013; Wrona and Reist, 2013). Other drivers causing changes and degradation of the Arctic ecosystems are ocean acidification, pollution, landscape disturbance, changes in currents, invasive species and exploitation of resources (CAFF, 2017). How these changes will affect biodiversity is poorly understood, but under future scenarios of climate change, Arctic habitats may be irrevocably lost (Michel, 2013). Food resources are being lost for many Arctic marine species; increasing numbers and diversity of southern species are moving into Arctic waters, and current trends indicate that the high Arctic marine species are under huge pressure. Species that depend on sea ice for reproduction, resting or foraging will experience range reductions. Arctic marine species and ecosystems are also undergoing pressure from changes in their physical, chemical and biological environment (CAFF, 2017). While there are few time series available that date back to the 1950s and 1960s, an analysis of the Arctic Species Trend Index data by decade indicated that the proportion of locations with decreasing populations has grown from 35% in 1950-1960 to 54% in 2000-2010 (Bohm *et al*., 2012; McRae *et al*., 2012). Awareness of the profound changes in the Arctic has also been improving thanks to the establishment of several Arctic Long-Term Ecological Research sites, especially since the late 1990s when more detailed and across ecosystem analyses was implemented (Soltwedel *et al*., 2016).

Several marine mammal species were historically hunted in the Arctic, with some overharvested such that populations were depleted (e.g., bowhead whale *Balaena mysticetus*) or driven extinct (e.g., Steller's sea cow *Hydrodamalis gigas*). Regulation of these activities has led to stabilization or recovery of some populations of some species (Jorgensen *et al*., 2016). The Circumpolar Biodiversity Monitoring Program has identified 32 Focal Ecosystem Components to use as indicators of ecosystem state. For marine mammals for example, an assessment of 84 stocks of 11 species indicated that eight are increasing, 14 are stable, four are decreasing, but for the remaining 53, trends are unknown. The most dramatic cases are for polar bear *Ursus maritimus*, for which seven out of 19 populations are declining, four are stable, and only one is increasing (Reid *et al*., 2013). Another example is the Cook Inlet beluga whale *Delphinapterus leucas* population, which declined in the 1990s and still remains Critically Endangered (Jorgensen *et al*., 2016). For terrestrial carnivores, trends vary among species, populations and regions, ranging from increases to local extirpation, while for herbivores, populations fluctuate through time, independently of human stressors (Reid *et al*., 2013). With regards to birds, most of the Arctic species are migratory and therefore their population trends are affected by drivers (e.g., food availability, habitat loss) across their migratory routes. Some migratory populations are known to have increased (e.g., many Nearctic and Western Palearctic waterfowl populations, especially geese), while others have decreased (e.g., in the Eastern Palearctic). For resident bird species, trends are poorly known (Ganter & Gaston, 2013). For most seabird populations, trends have been negative (Jorgensen *et al*., 2016) or are difficult to assess due to lack of information. Particularly for geese populations, it is suspected that those species with the poorest information are those with the greatest declines (CAFF, 2018). For amphibians and reptiles, there are no reports of declines, but data are very scarce (Kuzmin & Tessler, 2013). For freshwater fish species, about 28% are under threat (e.g., the five sturgeon species), while for marine species, population trends cannot be inferred due to the lack of data except for a few commercial species (Christiansen & Reist, 2013). Fisheries and bycatch are the main threats to marine fishes and occur mostly in the shelf areas connecting the Arctic to boreal regions of the Atlantic and Pacific Oceans (e.g., the Barents Sea and Bering Sea). It is expected that as the waters continue to warm, fishing activities will spread to previously unfished Arctic regions. For phytoplankton, zooplankton and benthic invertebrates, there is insufficient information to infer trends, but there are a few documented cases of the negative effects of anthropogenic activities on population size, abundance, growth and species distribution (Gradinger *et al*., 2010; Jorgensen *et al*., 2016). Overall, current monitoring is not sufficient to determine status and trends for most Focal Ecosystem Components (CAFF, 2017).

Protected areas within the CAFF boundary cover 20.2% of the Arctic's terrestrial area and 4.7% of the marine area, which is almost two and four times the terrestrial and marine areas protected in 1980 respectively. Combined, these areas and cover 3.7 million km^2 and 11.4% of the Arctic. The effectiveness of the management of these areas, and their levels of governance vary across countries. While this represents progress towards policy goals, these protected areas still do not represent all ecologically relevant ecosystems, cover all important sites for biodiversity, or meet other aspects of Aichi Target 11 within the Arctic region (Barry *et al*., 2017; CAFF & PAME, 2017).

3.5 CROSS-CUTTING SYNTHESIS OF TARGET ACHIEVEMENT

To identify broad patterns of progress towards the Aichi Biodiversity Targets and SDGs, we first identified thematic groups of Aichi Biodiversity Targets and SDG targets based on an assessment of the relationships between each target and the different components (nature and NCP) of the IPBES conceptual framework (see chapter 1). We then synthesized the patterns of progress presented in sections 3.2 (on Aichi Biodiversity Targets), 3.3 (on SDGs) and 3.4 (on other biodiversity agreements) for each of these themes. As most other agreements endorse the Aichi Biodiversity Targets (see sections 3.4 and S3.9), we assumed alignment of individual targets of these agreements with the Aichi Biodiversity Targets.

To identify themes that are cross-cutting across the Aichi Biodiversity Targets and SDGs, we carried out an expert-based classification exercise to assess the relationships between the targets/goals and two main elements of the IPBES conceptual framework (nature and NCP). For the SDGs, we scored both the goals and the most relevant targets within them. Scores rating the direction and the strength of the relationships were assigned in a Delphi process involving 31 authors of the IPBES global assessment and refined by a smaller core team of four experts. Based on these scores, nine broad thematic groups of targets and goals were identified **(Figure 3.16)**. These thematic groups (themes) identify cross-cutting commonalities that emerge across various multinational environmental agreements in terms of the IPBES conceptual framework. Each theme contains only the most dominant targets that are considered cross-cutting across the SDGs and Aichi Biodiversity Targets (derived from the scoring exercise). Other related targets are considered to complement the discussion relating to the theme. Progress in achieving targets within the themes is summarized in the following paragraphs. It is to be noted that we synthesize results of assessments on progress towards the Aichi Biodiversity Targets and other biodiversity agreements and on trends in nature and NCP relating to achieving

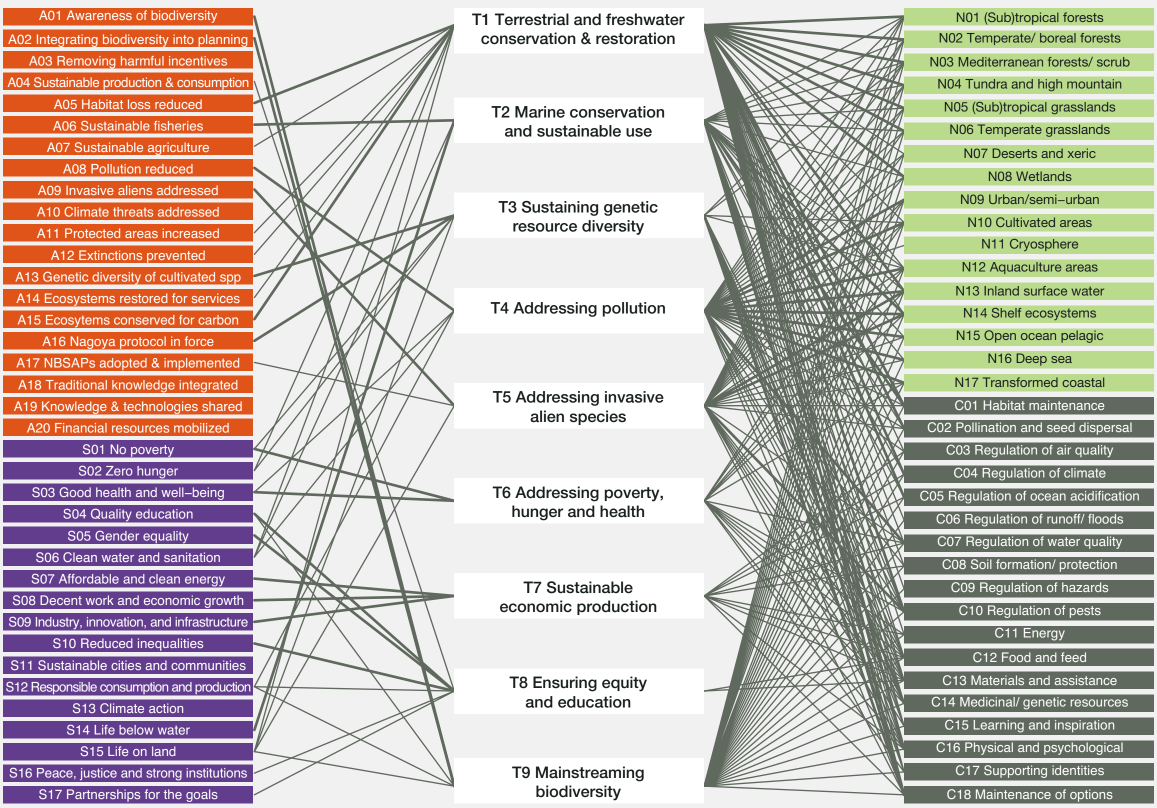


Figure 3 16 **Nine themes cutting across the Aichi Biodiversity Targets, SDGs and other related multilateral environmental agreements.**

These themes were defined through their relationships to targets of major environmental agreements (Aichi Biodiversity Targets, Sustainable Development Goals), and elements of the IPBES conceptual framework (nature and nature's contributions to people) in a cluster analysis exercise (see section S3.13). The thickness of the lines indicates a degree of association. Only targets significantly associated with each theme are shown.

the SDG targets. The term 'progress' is therefore used in a broad sense, encompassing trends related to the individual agreement goals/targets. Details of the expert-based scoring and the statistical analysis of the results are documented in S3.13, Figure S3.1, Table S3.9, Table S3.10, and Table S3.11 in the Supplementary Materials.

1. Terrestrial and freshwater conservation and restoration

This theme brings together goals and targets related to the conservation and restoration of terrestrial and freshwater ecosystems. It includes measures to conserve threatened species and actions to ensure the integrity of ecosystems. Apart from cross-cutting targets of Aichi Biodiversity Targets 5 (habitat loss, degradation & fragmentation reduced) and 15 (conservation and restoration of ecosystems for carbon) and SDG target 15.1 (freshwater ecosystem conservation), other targets associated with this theme include Aichi Biodiversity Targets 11 (protected areas etc.), 12 (extinctions prevented & threatened species conserved), 14 (ecosystems providing services restored and safeguarded), SDG target 6.6 (protect and restore water-related ecosystems), and several other targets from SDG 15 (e.g., 15.2, 15.3 and 15.5). Relevant targets and goals from other conventions such as the UNCCD, Ramsar Convention, CMS and the ITPGRFA also reinforce achieving conservation of terrestrial resources and ecosystems.

This group of targets receives considerable attention from policymakers, as most human activities happen on land, from agriculture to urbanization, among others. Several NCP, material goods and cultural contexts of nature are linked to ecosystems and resources on land including species, water and green spaces. Progress across relevant targets is varied. For instance, for some elements of some targets (such as protected area coverage) there has been good progress, while progress has been poor to moderate in others such as those relating to effective management and coverage of areas of importance for biodiversity, ensuring sustainable production and management systems in sectors such as agriculture and forestry, ensuring health, food and water security, reducing species declines, and building resilience of vulnerable populations (see sections 3.2,2, 3.2.3, 3.4.2, 3.4.3). This is reinforced by results from other relevant biodiversity related agreements such as the UNCCD, CITES, CMS, Ramsar Convention on Wetlands, and the IPPC (section 3.4). That said, better standards for phytosanitary measures in trade in biological resources and efforts to improve compliance with CITES measures are showing moderate progress. Some of the major drivers of land use change have been the impacts of urbanization and increasing consumption, which has resulted in high ecological footprints with increasing pressures on all resources.

Several of the targets do not have sufficient data to assess trends (e.g., reduction in disasters, access to green spaces). Moderate progress is reported in the achievement of targets towards conservation of natural and cultural heritage, which is also reflected in the progress towards the achievement of the goals of the Convention concerning the protection of the World Cultural and Natural Heritage (section 3.4).

Overall, more concerted and synchronized efforts are required to ensure that local actions can be implemented considering both policy goals and local priorities. This links also to raising awareness, building capacities of different actors in an inclusive and reflexive manner, and providing relevant incentives and disincentives to trigger appropriate action towards sustainable use and management of terrestrial ecosystems.

2. Marine conservation and sustainable use

This theme emphasizes the need for specific attention and actions relating to the oceans and marine ecosystems to ensure conservation and sustainable use of marine resources through actions including regulation of fisheries and appropriate incentives to ensure the health of marine ecosystems. The theme reaffirms the close linkages between human well-being and the health of the oceans. It is captured across the Aichi Biodiversity Targets (6 on sustainable fisheries) and SDGs (14 on life below land) and other conventions related to the oceans.

Progress and trends towards goals related to marine conservation and restoration vary from poor to moderate. Some significant steps have been made in the implementation of umbrella conventions such as the UN Convention on the Law of the Sea (UNCLOS), the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) and the United Nations Fish Stocks Agreement (UNFSA), but marine biodiversity and ecosystems continue to face multiple threats from human activities, including habitat loss, pollution, human disturbance, unsustainable and unregulated fisheries and climate change. Measures such as managing trade, expanding marine protected areas, and developing guidelines for no-fishing zones (through conventions such as CITES or reporting guidelines of FAO, the Convention on Biological Diversity (CBD) and the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) have had some positive effects. However, it has also been noted that focus is often paid to the conservation of certain marine species, which impedes conservation efforts of other species (see sections 3.2.2; 3.4.2 and **Boxes 3.1, 3.2**). The consequences of coastal and deep-sea fishery stock depletion and ecosystem degradation has had negative consequences for the well-being of IPLCs in terms of food security, spiritual and social integrity and livelihoods. Furthermore, despite the long associations and interactions between IPLCs and oceans, the knowledge and experience of IPLCs has largely remained untapped in designing conservation and management strategies (see sections 3.2.4; 3.3.3).

3. Sustaining genetic resource diversity

This theme focuses on the basic units of life that provide diversity to life forms and options for the future (whether as food, medicine, materials, etc) and on incentives to ensure this diversity is maintained. It is the specific focus of Aichi Biodiversity Targets 13 (genetic diversity of cultivated species and wild relatives) and 16 (Nagoya Protocol), and SDG targets 2.5 and 15.6 (on prioritising genetic diversity of crops and promoting fair and equitable benefit-sharing respectively), suggesting that human well-being is connected to ensuring existence and access to diverse germplasm. It also emphasises the importance of ensuring that accessing these resources and generating benefits are achieved with the full, informed participation of all stakeholders in a manner that can be considered equitable. Implementing the Nagoya Protocol requires acknowledging the merits of traditional knowledge and practices for management of biodiversity and ecosystems.

Insufficient progress is being made in safeguarding the genetic diversity of plants, animals and their wild relatives, which require, greater effort to document the patterns of this diversity, and greater participation of local actors such as IPLCs to actively conserve germplasm in the form of landraces or native cultivars (see 3.2.4 3.3.2; 3.3.3). Little progress is also reported in related targets to end illegal trade of protected species, although institutional efforts are being strengthened (section 3.3 and section 3.4.2). It is noteworthy that the trends towards achieving genetic diversity targets are mixed, with positive trends noted in some crops and negative for others and livestock diversity. Targets such as SDG 2.3 (double productivity and incomes of small-scale producers) will need to be carefully implemented in the light of potential negative impacts if the pathways chosen increase intensive agriculture and mono-cropping practices. Local experiences illustrate that given adequate support; it is possible to achieve these various targets (see section 3.2.3; 3.3.2).

There has been moderate progress in the achievement of targets related to access to genetic resources and equity in sharing benefits arising from their use (Aichi Target 13 and SDG target 15.6), which are directly linked to equity and fairness. It is pertinent that the major indicator used to track equity is the number of countries that have ratified the Nagoya Protocol. Although much progress has been reported on the Access and Benefit-Sharing Clearing-House Mechanism (ABSCH) on national implementation, including legislative measures and monetary and non-monetary benefit-sharing, specific indicators capturing such information are still to be developed and included in the assessment of progress towards the targets. The ITPGRFA also deals with accessing genetic resources and benefit-sharing for selected food and agricultural crops through a well-functioning system of exchange of plant genetic resources for food and agriculture (PGFRA) from *ex situ* collections to different users. Furthermore, benefit transfers to providers of resources is developing through a mix of donations and payments for access to germplasm collections (see S3.10).

4. Addressing pollution

This theme focuses on pollution, its relationship with nature, good quality of life and the regulatory functions of NCP. It focuses also on the need to reduce pollution for healthy lives through appropriate clean production. It is seen as an area to be addressed in other conventions such as the Ramsar Convention, IPPC and the UNCCD in order to address their specific objectives too.

Pollution is one of the most important drivers that affects ecosystem integrity, species populations and human well-being. Aichi Target 8 (reduce pollution) and SDGs 3.9 (reduce deaths and illnesses from pollution) 6.3 (improve water quality by reducing pollution) and 14.1 (reduce marine pollution of all kinds) specifically aim to tackle this issue. While the adverse effects of pollution are well understood, actions towards addressing various types of pollution (air, water, soil, ocean etc) through different interventions have resulted in poor to moderate progress and trends to achieving the targets. Assessment of trends are also impaired due to inadequate data (either globally or regionally) on the links between pollution and quality of life, (e.g., SDG 3). Overall, despite the availability of appropriate technologies and high levels of awareness of the problems of pollution to nature, NCP and human well-being, there has been insufficient progress towards these targets globally (see sections 3.2, 3.3 and **Figure 3.13**)

5. Addressing invasive alien species

This theme brings together targets (Aichi Target 9 on invasive alien species identified and addressed and SDG 15.8 on reducing the impacts of invasive alien species) that focus on restricting the spread and impacts of invasive alien species, which cause significant ecological, economic and social impacts in most regions (see also chapter 2.1 and 2.2). This theme is linked to other indirect drivers such as the movement of resources due to trade (legal and illegal) or migration, and hence progress to achieving associated goals and targets is reliant on progress in implementing measures related to these drivers. Specific targets to tackle invasive alien species are also included in other conventions such as the Ramsar Convention on Wetlands.

While encouraging progress has been made in implementing eradications of invasive alien species (at least on islands), with substantial benefits to native species, poor progress has been reported in the achievement of targets related to containing and reducing the spread and impact of invasive alien species, with countries reporting this to be one of the least achieved targets (section 3.3; 3.4). Little progress has also been reported on the integration of ILK into implementation, despite evidence from the ground of the benefits of such an approach (sections 3.2.3, 3.3.2. Overall, while there are local examples of good practices to ensure the integrity of ecosystems, determined efforts are needed to address various dimensions that impact ecosystem integrity.

6. Addressing poverty, hunger and health

This thematic group brings together three of the most critical well-being needs of people: sustained and sufficient income, food and nourishment and the ability to lead healthy lives. These emerge as a set of cross-cutting topics that are sought to be achieved explicitly in the SDGs (Goals 1, 2, 3) and also given importance within the Aichi Biodiversity Targets (Target 14), and further impacted by policies implemented through other MEAs including the Ramsar Convention, ITPGRFA and CITES. Achieving these different goals hinges on the availability and access to various material, regulating and non-material contributions from nature, and anthropogenic assets including technology, knowledge and institutions.

Most targets and goals in this theme are from the SDGs, and trends towards achieving them vary from negative to insufficient. Poverty, malnourishment and health security continue to be major challenges encountered especially by socially vulnerable populations, and this may relate to lack of rights to access and utilize resources and benefits from them (see also section 3.2.3). It has been observed that even while some quality of life parameters show improvement in the short term, indicators relating to the supporting elements from nature and NCP show declining trends, indicating unsustainable development pathways (see sections 3.3; 3.4).

7. Sustainable economic production

This theme captures good quality of life elements including targets to ensure decent work and economic growth, access to affordable and clean energy for these purposes and innovation for sustainable production activities, including infrastructure (SDGs 8, 7 and 9 respectively). These activities also act as drivers to the utilization of ecosystems, resources and how nature's contributions to people can be sustained.

For many SDGs, the pathways chosen to achieve the targets will have impacts (positive and negative) on nature and the sustainable provision of its contributions to people, with far-reaching impacts on other SDGs, particularly the case for Goals 7, 8, 9, 12. New approaches to achieve these goals are available that can have positive impacts (such as growing demand for 'green' products). Assessing progress towards this theme is also limited by availability of relevant information and appropriate indicators. While the targets are of high relevance to IPLCs, unsustainable resource extraction for various production uses has resulted in many conflicts, including over the production of biofuels, other energy and mining. Overall trends are negative in achieving the various targets related to this theme (see section 3.2.3).

8. Ensuring equity and education

This theme focuses attention on several of the less tangible good quality of life elements such as education on sustainable development, ensuring inclusive development, ensuring peace and justice, ensuring equitable access to basic necessities such as food and resources, measures such as reducing waste of resources, and building operational and supportive partnerships between different actors. Achieving various targets under these goals also has consequences for desirable actions needed to achieve goals related to sustainable economic production. These have been identified as necessary to address targets pertaining to various dimensions related to nature, nature's contributions to people and good quality of life.

Measuring progress towards this theme is generally constrained by availability of sufficiently developed indicators. Still, a general inadequacy in having participatory and inclusive approaches in planning and design for both conservation and development policies appears to have stymied efforts to address various issues related to their effective implementation. Overall, despite advances in technologies and the presence of multiple policies to address human well-being and sustainability, trends still appear negative towards achieving relevant targets on this theme, requiring more focused and inclusive actions are required if we are to reach these goals.

9. Mainstreaming biodiversity

This theme focuses on targets and goals on including biodiversity and ecosystems in planning processes and thereby integrating the values of biodiversity across sectors and decision-making. Goals and targets included are those relating to awareness of biodiversity, integration of biodiversity in planning and sustainable development actions. This is a recurrent theme in most other Conventions including Ramsar, CMS, UNCCD and others.

Progress in mainstreaming actions vary from medium to low. Certainly, efforts to generate more awareness about biodiversity and ecosystems to sustain life and human well-being are being strengthened (sections 3.2, 3.3). However, adoption into planning processes is still lagging, indicated by a general inadequacy in ensuring coherence between sectoral policies such as for instance ensuring that urban planning is aligned with availability of green spaces, human health, food security and diversity in a changing climate. Progress in other associated targets and goals that pertain to actions across various sectors of production, consumption, conservation of biological and cultural diversity, innovation, equitable partnerships, and financial support further accentuate that more efforts are required to achieve good progress in this theme.

3.6 REASONS FOR VARIATION IN PROGRESS TOWARDS POLICY GOALS AND TARGETS

As shown in the preceding sections, there is a high degree of variation in progress towards meeting the goals and targets of Aichi, SDGs and other Conventions. This variation occurs between targets (i.e. some targets have greater progress than others), as well as between regions (i.e. some regions show greater progress than others towards particular targets, although information on this was available only for a subset of indicators and Aichi Biodiversity Targets). A review of the literature shows that multiple factors contribute to variation in the achievement of goals and targets. These factors can be broadly categorized as follows:

Biophysical and socioeconomic conditions: The distribution of biodiversity, socioeconomic status and development trajectories vary substantially between countries. This variation has implications for the ability of countries to meet specific policy targets (Robinson *et al*., 2009). However, the relationships between biodiversity, development and conservation or sustainable use are not simple or linear, and are often impacted by historic development, legacy effects and cross-scale dynamics and feedbacks from other countries and regions (Raudsepp-Hearne *et al*., 2010).

Human, institutional and financial capacity: These capacities are critical to the overall ability of nations to develop and implement plans and actions to achieve any given goal or target (Nowell, 2012; Reeve, 2006). For example, an analysis of a global database of hundreds of marine protected areas (MPAs) showed that the ability of MPAs to protect biodiversity was not only a function of environmental factors (e.g., ocean conditions) or of aspects of the MPA itself (e.g., size or regulations), but also dependent on the MPA's human and financial capacity (Gill *et al*., 2017).

Norms and values: Rands *et al*. (2010) suggest that, in addition to resources, the will to achieve a goal is critical for its actual achievement. Unfortunately, this is often overlooked; policy responses to biodiversity loss often fail to establish the institutions, governance, and behaviours necessary for achieving the specific targets and objectives of Conventions (Geldmann *et al*., 2018; Rands *et al*., 2010). The concept and value of biodiversity is often articulated or measured differently between different groups of people or across different regions (Gotelli & Colwell, 2001). Consequently, goals or targets that can incorporate multiple perspectives on biodiversity and its benefits, or which take into account local values, are more likely to resonate with key local stakeholders and to receive greater attention and, as a result, they are more likely to be achieved (Anthamatten & Hazen, 2007; IPBES, 2015; Pascual *et al*., 2017).

Governance and institutions: Building on previous results showing that governance is an important predictor of biodiversity loss (Smith *et al*., 2003), deforestation rates (Umemiya *et al*., 2010), protected area effectiveness (Barnes *et al*., 2016) and poaching (Burn *et al*., 2011), a recent analysis found that the governance quality explained substantially more variation in investment in biodiversity conservation than did direct measures of wealth (Baynham-Herd *et al*., 2018).

The focus and formulation of the target: The goals and targets assessed link to nature in different and complex ways, and, due to the complex interrelationships in socio-ecological systems, are themselves also interconnected and interdependent (Nilsson *et al*., 2016). Certain types of goals and targets may, therefore, be easier (or harder) to achieve than others. Some, such as Aichi Target 12 (preventing extinctions), are highly dependent on achievement of other targets (such as Target 5 addressing habitat conversion, Targets 6 and 7 on sustainable production, Targets 8 and 9 on particular drivers such as invasive alien species and pollution, and Target 11 on protected areas; see section 3.2). A review of efforts in Canada to meet the Aichi Biodiversity Targets found that implemented responses tend to be associated with targets that have specified levels of ambition or that are more straightforward to achieve (e.g., knowledge capacity and awareness) (Hagerman & Pelai, 2016). By contrast, targets addressing equity, rights or policy reform were associated with fewer actions, presumably because of less effective target design combined with a lack of fit within existing institutional commitments (Hagerman & Pelai, 2016). Furthermore, it may be harder to meet goals and targets that require global collaboration than it is to meet those achieved primarily through local action (Mazor *et al*., 2018). A recent review of the Aichi Biodiversity Targets strongly suggested that the articulation and framing of the targets may influence their achievements (CBD 2018c). The study found that significantly greater progress has been made towards targets that are considered more measurable, realistic, unambiguous and scalable, and targets that best adhered to the principals of 'SMART' objectives (i.e., Specific, Measurable, Ambitious, Realistic and Time-bound) were those that contained explicitly defined deliverables (CBD, 2018c). This is consistent with previous assessments that suggested that the degree to which progress can be measured may impact progress (Butchart *et al*., 2016; Campagne, 2017; CBD 2018c; Kenny, 2015; Moldan *et al*., 2012; Tittensor *et al*., 2014). Lack of robust data (Wood *et al*., 2008), incomplete datasets, dependency on self-reporting and shortfalls in the human and financial capacity to generate, analyse and report on progress (Nowell, 2012) also hinder the ability to measure progress and may in turn therefore impede achievement of goals and targets.

We found no consistent regional patterns of variation in progress towards the Aichi Biodiversity Targets, with some regions achieving greater progress than others towards particular targets (section 3.2.3. For example, there appeared to be greater progress towards Aichi Target 19 (on improving and sharing biodiversity knowledge and technologies) in the Americas, but slower progress for Targets 5 (on loss of natural habitats) and 11 (on protected areas). However, data constraints meant that this assessment was based on a limited set of indicators and only a subset of Aichi Biodiversity Targets. Due to the size of IPBES regions, the mixed patterns of progress and the limited scale of the regional assessment conducted, no clear factors emerged as important in determining regional differences in progress. It is likely that multiple factors are relevant in national and regional contexts with implications for target achievement. Regional variation in progress towards other conventions, as well as in the impacts of trends in nature and NCP on progress to the SDGs, was not assessed owing to insufficient regionally disaggregated information and indicators.

Consistent differences in progress were more apparent between different goals and targets. There has been greater progress towards goals and targets related to policy responses and actions to conserve nature and use it more sustainably than towards goals and targets addressing the drivers of loss of nature and NCP. Consequently, there was generally poor progress towards Targets aiming to improve the state of nature and aspects of NCP (**Tables 3.8** and **3.9**; **Figures 3.7, 3.8, 3.19**). For example, there has been good progress on responses such as eradicating invasive alien species (at least on islands; Aichi Target 9), expanding protected areas (albeit with caveats about their location and effectiveness; Aichi Target 11), implementing the Nagoya Protocol (Aichi Target 16), developing NBSAPs (Aichi Target 17), implementing plans for sustainable urbanization and climate action (SDGs 11 and 13), and efforts to conserve and sustainably use ecosystems (SDGs 14 and 15), and sharing information and coordinating between MEAs (see sections 3.2, 3.3, 3.4). Despite this, indicators show that the drivers of biodiversity loss are increasing, and hence progress towards goals and targets to reduce these pressures has been generally poor. For example, freshwater, marine and urban pollution is increasing (Aichi Target 8, SDGs 6, 14 and 11), invasive alien species are increasingly having negative impacts (Aichi Target 9, SDGs 14 and 15), and drivers associated with unsustainable agriculture, aquaculture, forestry and fisheries are increasing pressures on nature and its ability to deliver NCP (Aichi Target 5, 6, 7, SDGs 12, 14, 15; sections 3.2 and 3.3).

As a result of the progress towards targets addressing drivers being insufficient, despite positive progress to targets addressing responses to biodiversity loss, progress to targets aiming to improve the state of biodiversity has been poor. For example, natural habitats continue to be lost, species' abundance is declining, and extinction risk trends are deteriorating (Aichi Biodiversity Targets 5 and 12, SDGs 14 and 15; sections 3.2 and 3.3). Trends in the magnitude of NCP are less well known, but four of five indicators used to assess progress towards Aichi Biodiversity Targets show significantly worsening trends (section 3.2). The NCP-dependent cluster of SDGs (1, 2, 3 and 11, addressing poverty, hunger, health and well-being, and sustainable cities) showed similarly negative impacts of declines in NCP (section 3.3).

This disconnect between progress in responses and increases in drivers of change in nature and NCP requires consideration. There is not a simple linear relationship, owing to several reasons. First, from a small set of counterfactual studies and other assessments (e.g., Geldmann *et al*., 2013; Hoffmann *et al*., 2010, 2015; Jones *et al*., 2016; Waldron *et al*., 2017), trends in drivers and the state of nature would be worse without the conservation responses that have been implemented (section 3.2). Second, the responses assessed are only a small set of sectorally limited responses out of many possible and necessary responses required to stem the drivers of loss in nature and NCP. For example, approaches to achieve several of the SDGs on climate, energy, economic growth, industry, and consumption and production (7, 8, 9, 12, 13) are likely to have a substantial impact on trends in drivers including pollution, habitat loss and degradation, invasive alien species, and on the state of nature and NCP, requiring more than just protected areas to prevent impacts (Maron *et al*., 2018). Third, many of the targets track responses at the planning or policy level, rather than the actual enforcement and implementation level, implying that the responses may be less effective than assessed at stemming drivers and loss of nature. For example, the extent of protected areas has grown considerably, but their effectiveness is often insufficient (e.g., Clark *et al*., 2013; Gill *et al*., 2017; Marine Conservation Institute, 2017; Schulze *et al*., 2018; section 3.2). Finally, there is the potential for mismatches (spatially, temporally and sectorally) between responses and drivers, made more complex by telecoupling—interactions between distant places—which are increasingly widespread and influential, and can lead to unexpected outcomes with profound implications for our ability to meet global goals for sustainability (Liu *et al*., 2013). Policy coherence across sectors and scales, at the heart of Agenda 2030 and the SDGs, will better account for different trade-offs between these interdependent goals and targets.

While there is a considerable body of literature on the potential explanations for variation in achieving goals in particular locations or achieving a particular goal in multiple regions, the existing literature is notably lacking in synthetic understanding of the reasons for variation. Improving understanding and evidence of these reasons for variation in progress towards goals would help achieve greater success in future.

3.7 IMPLICATIONS FOR DEVELOPMENT OF A NEW STRATEGIC PLAN ON BIODIVERSITY AND REVISED TARGETS

The Strategic Plan on Biodiversity 2011–2020, adopted under the CBD, proposed ambitious biodiversity-related targets to be achieved by 2020 (CBD, 2010a). Here we discuss implications for any follow up to the plan (proposed by CBD, 2016a) such as a revised version with new or revised targets. We based this on considerations from the challenge of assessing progress towards the existing Aichi Biodiversity Targets (section 3.2 above), as well as towards SDGs (section 3.3) and the goals of other Conventions related to nature and nature's contributions to people (section 3.4), and secondly based on the considerations of the progress achieved or lack thereof (drawing on these three sections plus the cross-cutting synthesis in section 3.5 and discussion of reasons for variation in progress in section 3.6). Additional considerations when setting revised targets include the need for suitable language and wording to engage stakeholders and inspire action, socio-economic transformations for sustainable consumption, transformative changes and governance (see below and chapter 6), and to illustrate the importance of tackling a particular issue in order to address biodiversity loss. However, these aspects have been rarely addressed in the literature to date. Finally, it may not be possible for a particular future target to take full account of all of the points below, but their consideration across the whole suite of targets will hopefully strengthen any future version of the strategic plan.

Future targets with clear, unambiguous, simple language, and quantitative elements are likely to be more effective. Some of the existing Aichi Biodiversity Targets are difficult to interpret because they have ambiguous wording, undefined terms that are open to alternative interpretations, unquantified elements with unclear definitions of the desired end point, unnecessary complexities, and redundant clauses (Butchart *et al*., 2016; CBD 2018c). Of the 20 Aichi Biodiversity Targets, 70% lack quantifiable elements (i.e., there is no clear threshold to be met for the target to be achieved) and 30% are overly complex or contain redundancies (Butchart *et al*., 2016). For example, Target 7 calls for areas under agriculture, aquaculture and forestry to be 'managed sustainably', without providing any quantification in relation to sustainability. This makes it more challenging to determine the necessary actions to achieve them, to coordinate these across Parties, and to assess progress towards achieving them (Butchart *et al*., 2016; CBD, 2018c; Maxwell *et al*., 2015; Stafford-Smith, 2014), although vague wording may make it easier to achieve consensus in some contexts (Maxwell *et al*., 2015). Using simple succinct language in targets, and providing explanations, definitions and caveats in background documents, guidance, and preambular text, would be beneficial (Butchart *et al*., 2016; CBD, 2018c). Quantification, however, will be only helpful if it focuses on the most appropriate metrics (see below in relation to protected area coverage).

Future targets that more explicitly account for aspects of nature or NCP relevant to good quality of life will be more effective at tracking the consequences of declines in nature and NCP for well-being, as well as better able to support future assessments of implications for SDG achievement. The assessment of SDG targets concluded that while nature and NCP were known to be important for goals related to education, equity, gender equality, and peace; a current lack of targets capturing these aspects of nature made an assessment of implications for these SDGs not currently possible. Clearer formulation of targets which capture the contributions of nature to these important development goals, will not only support improved assessments, but also foster new knowledge and evidence of these complex linkages. Similarly, the assessment of SDGs 1, 2, 3 on poverty, hunger and health respectively was limited to a few targets capturing the contributions of nature to these goals, however a wider set of contributions is known to exist but not currently assessed due to this gap.

Future targets may be more effective if they take greater account of socioeconomic and cultural contexts. Targets focused on equity, rights, or policy reform for better governance and sustainable economies (see chapter 6 section 6.4) appear to have resulted in fewer actions than other targets, mainly because of a lack of fit within existing institutional commitments (Hangerman & Pelai (2016), and perhaps because they are more difficult to achieve. Increasing consideration of values, drivers, and methods of valuation in the context of policies and decision-making when setting targets may also help to reduce lack of political cooperation, inadequate economic incentives, haphazard application of policies and measures, and inadequate involvement of civil society (Ehara *et al*., 2018; Hangerman & Pelai, 2016; Meine, 2013). For example, it has been argued that there is a need for frameworks and tools for understanding and acting upon the linkages between human rights, good governance and biodiversity (Ituarte-Lima *et al*., 2018). Targets may be easier to interpret if they are more explicit about the socioeconomic and cultural contexts that determine the pathways through which the outcome should be achieved, to avoid undesirable socioeconomic consequences (e.g., protected area expansion or establishment taking into account the impacts on IPLCs; Agrawal & Redford, 2009) or negative impacts on different cultures.

Future target setting will be more inclusive if it integrates insights from the conservation science community, social scientists, IPLCs, indigenous and local knowledge, and other stakeholders. For example, conservation scientists can help to establish ecologically sensible protected area targets and to identify clear and comparable performance metrics of ecological effectiveness (Watson *et al*., 2016a). However, to take into account governance issues and trade-offs between ecological, economic, and social goals, inputs and perspectives from social scientists, indigenous and local knowledge, and non-academic stakeholders from all regions are also needed (Balvanera *et al*., 2016; Bennett *et al*., 2015; Larigauderie *et al*., 2012; Martin-Lopez and Montes, 2015). Socioeconomic and cultural contexts are often not considered when targets or indicators are proposed. In particular, Hangerman & Pelai (2016) suggested that targets focused on equity, rights, or policy reform were associated with fewer actions mainly because of lack of fit within existing institutional commitments rather than because of a lack of effective target design. It is important to consider epistemological and ethical pluralism (instead of the predominant ethical monism of Western cultures) when discussing values, consumption patterns, and alternative economic models in the context of policies, decision-making and target setting (see section 6.4 of chapter 6).

Finally, it has been suggested that a future version of the strategic plan could consider highlighting fewer and more focused headline targets (including those focused explicitly on retention of biodiversity; Maron *et al*., 2018), alongside specific subsidiary targets capturing other elements. Such headline targets might highlight a set of specific actions for conservation of nature and NCP, e.g., ambitious, specific, quantified targets to reduce deforestation and wetland degradation, increase the sustainability of fisheries, minimize agricultural expansion, manage invasive alien species, increase the extent and effectiveness of protected areas (and their coverage of important sites for biodiversity), address ocean acidification, promote the recovery of threatened species, and increase financing, underpinned by more specific subsidiary targets covering other aspects of the existing Aichi Biodiversity Targets (Butchart *et al*., 2016; Maron *et al*., 2018). An alternative approach would be to retain and update all Aichi Biodiversity Targets, but focus on a subset such as those listed above for communications and publicity.

The failure to achieve some targets or particular elements of targets, alongside success in achieving other elements, also has implications for a new version of the strategic plan. Thus, targets that have not been achieved may require increased effort and/or new tactics, while the elements of targets that have been successfully achieved may require increased ambition and/or monitoring to detect and avoid potential regression. In this sense, time-bound targets could be considered as milestones in a process, rather than as final objectives. CBD (2018c) suggested that future targets should be ambitious but realistic, recognizing that ambition without realism can undermine confidence in the ability to deliver on targets, but equally that ambition also promotes and drives progress.

Future protected area targets that focus on enhancing coverage of important locations for biodiversity and strengthening management effectiveness may be more effective than simply setting a specific percentage of the terrestrial and marine environments to be conserved. In implementing Aichi Target 11, most focus has been on achieving the target percentages of terrestrial and marine area to be covered by protected areas (Barnes, 2015; Barnes *et al*., 2018; McOwen *et al*., 2016; Spalding *et al*., 2016; Thomas *et al*., 2014; Tittensor *et al*., 2014), at least partly owing to lack of explicit guidance on other aspects specified in target, for example on how to measure ecological representation, how to conserve through effective and equitable management, or how to define 'other effective area-based conservation measures' (OECMs). In particular, a focus on the area percentage may have distracted from the need to locate protected areas to cover effectively 'areas of particular importance for biodiversity' such as Key Biodiversity Areas (Butchart *et al*., 2012, 2014; Edgar *et al*., 2008; Juffe-Bignoli *et al*., 2014, 2016; Spalding *et al*., 2016; Tittensor *et al*., 2014), and to ensure that they are effectively managed (Barnes *et al*., 2015, 2018; Clark *et al*., 2013; Coad *et al*., 2015; Juffe-Bignoli *et al*., 2014, 2016b; Spalding *et al*., 2016; Watson *et al*., 2016b). While there have been calls for substantially higher area-based targets, tripling the current protected area network to cover 50% of the terrestrial surface (Baillie & Zhang, 2018; Dinerstein *et al*., 2017;Noss *et al*., 2012; Wilson, 2016; Wuerthner *et al*., 2015), these have also been criticized as being unfeasible and counter-effective in particular because they fail to consider the social impacts and the need to sustain protected areas socially and politically (Büscher *et al*., 2017). They may also deliver perverse outcomes (Barnes *et al*., 2018; Jones & De Santo, 2016), and if protected area expansion is concentrated in areas with low human influence, it is unlikely to conserve species diversity sufficiently (Pimm *et al*., 2018) or contribute to effective conservation outcomes (Magris & Pressey, 2018). While some efforts have been taken to operationalize other aspects of Target 11 (e.g., Faith *et al*., 2001; MacKinnon *et al*., 2015), any future protected area target may be more effective if it is structured to reduce the risk that areas with limited conservation value are protected at the expense of areas of biodiversity importance. In consequence, more effective nature conservation may be delivered by shifting the focus from efforts to achieve a pre-determined areal extent to efforts that achieve a specified biodiversity outcome (Barnes *et al*., 2018). This would require monitoring biodiversity outcomes and realistic targets and indicators taking account of financial and data constraints (Barnes *et al*., 2018). Alongside this, the terrestrial network of protected areas and OECMs will need to be substantially strengthened in order to conserve the most important sites for biodiversity while achieving ecological representation, improved effectiveness, better integration into the wider landscape and seascape, etc. (Butchart *et al*., 2015).

Future targets for marine protected areas may deliver better biodiversity benefits if they focus on management effectiveness in particular. Protection of marine areas is generally weak, even in wealthier nations (Boonzaier & Pauly, 2016; Shugart-Schmidt *et al*., 2015), with many marine protected areas being poorly enforced and ineffectively managed (Shugart-Schmidt *et al*., 2015). Management effectiveness may be enhanced through greater involvement of local stakeholders such as IPLCs (e.g., through the Locally Managed Marine Areas network; http://lmmanetwork.org/) and greater focus on key drivers such as pollution and unsustainable fisheries (see chapter 6). Increased consideration of the connectivity of marine protected areas is also needed (Lagabrielle *et al*., 2014; Toonen *et al*., 2013). In areas beyond national jurisdiction, future targets would focus on creating internationally recognized marine protected areas (Rochette *et al*., 2014). As in the terrestrial realm, a substantial scaling up of efforts, will be necessary to protect biodiversity, preserve ecosystem services, and achieve socioeconomic aims (O'Leary *et al*., 2016).

Future protected area targets may be more effective if they also explicitly address freshwater ecosystems and their processes, integrating nature and people, considering also the threats impacting them, and the actions needed to sustain them, including management strategies that consider connectivity, contextual vulnerability, and human and technical capacity (Juffe-Bignoli *et al*., 2016b).

A greater focus on protected area governance is important, including the implementation of participatory policies, improving institutional and community organization capacity, and consideration of self-regulatory management practices based on indigenous and local knowledge (Ramirez, 2016). Potential actions in this direction include: knowledge and capacity-building, valuation, improving policy frameworks, strengthening partnerships across sectors and engaging IPLCs (Dudley *et al*., 2015). Progress to date also suggests that understanding the expectations of all stakeholders can facilitate progress towards targets, and that equity issues between stakeholders can be explicitly considered (Hill *et al*., 2016). For example, for protected areas, participatory area management and spatial and temporal zoning can help to distribute benefits and costs equitably between stakeholders (Hill *et al*., 2016).

The implementation of future targets on conservation of species and sites could be more efficient through effective prioritization. Formal prioritization methods (which involve setting explicit objectives and incorporating the costs of actions, their probability of success, and the size of budget) allow cost-efficient implementation of actions to achieve targets (Visconti *et al*., 2015). For example, in the EU, focusing restoration efforts on habitats with unfavorable conservation status (as reported under the Habitats Directive) may provide the largest benefit for species and the delivery of NCP (Egoh *et al*., 2014). Many countries face the challenge of prioritizing with little capacity for biodiversity conservation and poor baseline data on most biological groups, requiring the development of better strategies for prioritizing based on changes in ecological, social and economic criteria (McGeoch *et al*., 2016) at the global, regional and local levels.

A new framework for biodiversity will be less effective if it does not explicitly address the implications of climate change for nature conservation. For example, many species, key biodiversity areas and protected areas will require adaptation plans to be developed and implemented, with actions coordinated across species' distributions and coherent strategies implemented across protected area and site networks (Hole *et al*., 2009). Potential unintended consequences of climate change mitigation efforts that may have negative impacts on biodiversity (e.g., displacement of food crop cultivation into natural areas as a consequence of biofuel expansion, or mortality of birds and bats from inappropriately sited wind-energy developments; Küppel *et al*., 2017; Oorschot *et al*., 2010; Schuster *et al*., 2015), need to be minimized. At the same time, the role of healthy ecosystems in helping people (particularly IPLCs) adapt to climate change ('ecosystem-based adaptation'; Munang *et al*., 2013), can be integrated into planning and policies.

Future targets may be more effective if they consider the availability of existing indicators and the feasibility of developing new ones. Close to the end of the period for achieving the Aichi Biodiversity Targets, some of them (Targets 15 and 18) still lack functional quantitative indicators entirely, while others lack indicators covering particular elements of the targets (**Table 3.3**; McOwen *et al*., 2016; Tittensor *et al*., 2014). In some cases, the paucity of indicators is because the targets are not particularly 'SMART' (specific, measurable, ambitious, realistic, and time-bound; CBD 2018c; Perrings *et al*., 2010). In a recent review, targets that scored higher on these characteristics were associated with greater progress (CBD 2018c). In some cases, although indicators may exist, their sufficiency and suitability for tracking progress are considered inadequate (Butchart *et al*., 2016; McOwen *et al*., 2016; Tittensor *et al*., 2014), e.g., owing to limited spatial, temporal or taxonomic coverage (Tittensor *et al*., 2014) and/or their alignment with the text of the target (McOwen *et al*., 2016; Tittensor *et al*., 2014). While existing or potential indicator availability is only one consideration when setting targets, without appropriate indicators, it is much more challenging to determine if progress has been made or if targets have been met (Butchart *et al*., 2016; CBD 2018c; McOwen *et al*., 2016; Tittensor *et al*., 2014).

Given the importance of adequate information and indicators for biodiversity based on robust datasets (Geijzendorffer *et al*., 2016), **sustained and augmented investment is needed to maintain, expand and improve knowledge products that underpin multiple indicators**, such as the *World Database on Protected Areas* (IUCN & UNEP-WCMC, 2017), the *World Database of Key Biodiversity Areas* (BirdLife International 2016b), IUCN Red Lists of threatened species and ecosystems (Brooks *et al*., 2015; Juffe-Bignoli *et al*., 2016a, Thomas *et al*., 2014) and the *Global Biodiversity Information Facility* (Jetz *et al*., 2012), alongside strengthened regional and global coordination and cooperation for data sharing and reporting (Knowles *et al*., 2015) and the development of new indicators to address key gaps.

A new version of the strategic plan is likely to be more effective if it gives greater emphasis to the trade-offs and synergies between targets. Efforts to achieve one particular target can contribute to achieving others (synergies) but may reduce the extent to which a different target may be achieved (trade-offs). For example, under Aichi Target 11, expansion of terrestrial protected area coverage could also contribute to reducing the loss of natural habitats (Target 5), reducing extinctions (Target 12), and maintaining carbon stocks (Target 15) (Di Marco *et al*., 2016b), but might have unintended consequences on good quality of life if people are displaced from new protected areas (Targets 14 and 18), especially if attention is not paid to the elements of the target relating to equitable management and integration into wider landscapes and seascapes. Similarly, different SDGs may have synergistic interactions or competing demands and critical trade-offs. Identifying these is an essential precursor to developing pathways for integrated and socially just governance processes (Mueller *et al*., 2017). For example, progressive changes in human consumption may improve biodiversity outcomes even in the absence of additional protection (Visconti *et al*., 2015). It will also be important to consider trade-offs related to the distribution of limited resources between multiple targets (i.e., expanding the use of natural resources to achieve economic development goals (Brunnschweiler, 2008). Identifying and securing synergies between targets, and minimizing trade-offs, would maintain options for co-benefits before they are reduced by increasing human impacts (Di Marco *et al*., 2016b). Evaluation of trade-offs is likely to vary depending on the criteria used, including in relation to social equity, models of economic growth, justice and fairness as well as biodiversity conservation (see chapter 6).

Trade-offs related to the distribution of limited resources between multiple targets is also an important point to be considered. Currently, most nations around the world are expanding the use of natural resources to achieve liberal economic development goals (Brunnschweiler, 2008; but see section 6.4, chapter 6). Consequently, rates of anthropogenic habitat conversion are rising in conjunction with biodiversity loss (Bianchi & Haig, 2013; Dirzo *et al*., 2014; Hansen *et al*., 2013; Watson *et al*., 2016a), while financial resources for conservation are limited, requiring effective prioritization of resources for actions addressing different and multiple targets (e.g., Polak *et al*., 2016; Venter *et al*., 2014). Finally, trade-offs may occur between different goals across spatial scales (i.e., the effects of the trade-off are felt locally or at a distant location) and temporal scales (i.e., the effects take place relatively rapidly or slowly) and these could also be considered and made explicit (Green *et al*., 2018; McShane *et al*., 2011; Rodríguez *et al*., 2006; see chapter 6).

Given that IPLCs manage or have tenure rights over a quarter of the world's land surface, an area that intersects with c.40% of all terrestrial protected areas and ecologically intact landscapes (Garnett *et al*., 2018), a revised strategic plan on biodiversity may be strengthened by taking account explicitly of the contribution of IPLCs to achieving and monitoring biodiversity goals and targets at local, national and international levels, integrating the importance of formal recognition of customary rights under national law (e.g., appropriate recognition of Indigenous and Community Conserved Areas and sacred sites, respect of free, prior and informed consent etc.), and recognizing the need to disaggregate indicators to quantify the contributions and impacts on IPLCs (Bennett *et al*., 2015; Hagerman & Pelai, 2016). Related to this, 'other effective area-based conservation measures' (as referred to in Aichi Target 12) have been argued to be essential for meeting more ambitious targets for conserving biodiversity in future (Dudley *et al*., 2018).

Maron *et al*. (2018) argue that future targets need to be explicit about the state of nature that meeting them is intended to achieve, noting that unquantified or rate-based targets can lead to unanticipated and undesirable outcomes. They propose the development of a series of area-based, quality-specific 'retention' targets to ensure adequate provision of key ecosystem services as well as biodiversity conservation.

Finally, Mace *et al*. (2018) suggested that tracking progress towards future biodiversity targets should focus on three aspects: near-future losses of species (i.e. extinctions, e.g., using the Red List Index), trends in the abundance of wild species (e.g., using population-level indicators such as the Living Planet Index) and changes in terrestrial biotic integrity (e.g., using the Biodiversity Intactness Index), although improved representativeness, integration and data coverage are needed for indicators for all three aspects.

3.8 KNOWLEDGE GAPS AND NEEDS FOR RESEARCH AND CAPACITY-BUILDING

There are clear gaps in available knowledge that have limited our ability to assess progress towards the Aichi Biodiversity Targets, Sustainable Development Goals, and the targets of other biodiversity-related conventions. Despite these limitations, we have enough information to recognize that biodiversity is declining due to complex, integrated social, economic and political factors (see chapter 6), and that actions are needed at the global, regional and local level to meet agreed policy objectives for sustainable development.

For our quantitative analysis of indicators to assess progress against the Aichi Biodiversity Targets, many potential indicators could not be included because they are available only for particular regions or have time series that are too short. The indicators that were included vary in their geographical and/or taxonomic coverage, as well as the degree to which they are aligned with targets, leading to variable levels of coverage (**Tables 3.3,** S3.1; Tittensor, *et al*., 2014). Existing indicators based on species' data are biased to better known groups, and underrepresent invertebrates, plants, fungi and micro-organisms. Among drivers of biodiversity loss, information is particularly poor for unsustainable exploitation e.g., spatial patterns in the intensity of hunting, trapping, and harvesting of terrestrial wild plants (Joppa *et al*., 2016). For 19 elements of 13 Aichi Biodiversity Targets, representing 35% of the elements and 65% of the targets, indicator datasets suitable for extrapolation were unavailable (e.g., relating to harmful subsidies for Target 3, and sustainability of management of areas under aquaculture for Target 7). Targets 15 (ecosystem resilience and contribution of biodiversity to carbon stocks) and 18 (integration of traditional knowledge and effective participation of indigenous and local communities) lack any suitable indicators that could be extrapolated, and hence progress on these Targets could not be assessed on the basis of indicator extrapolations. For Target 15, and elements of Targets 6 (on sustainable fisheries) and 14 (on ecosystem services), the lack of both quantitative indicators and qualitative information means that no assessment of progress was possible **(Figure 3.6)**. For Target 11 (site-based conservation and delivery of ecosystem services and equitable benefits from protected areas) there is insufficient information on trends in management effectiveness of protected areas, and inadequate quantitative information on the contribution of 'other effective area-based conservation measures' to meeting the target. For Target 12 (preventing extinctions), there is a lack of information (particularly on trends) for extinction risk of invertebrates and plants, and for trends in population abundance for species in tropical regions as well. There are gaps in our understanding of the relationship between indicators and the underlying system functions/ properties that they measure. There are also particularly few indicators relating to nature's contributions to people (**Table 3.3**; **Figure 3.5**; Tittensor *et al*., 2014). The sufficiency of indicators for the Aichi Biodiversity Targets (judged in relation to their alignment, temporal relevance and spatial scale) is lowest for Strategic Goal E (on enhancing implementation through participatory planning, knowledge management and capacity-building) (McCowen *et al*., 2016).

New indicators for such aspects will need to be developed for assessing progress under a post-2020 global biodiversity framework (CBD 2018d), and this will require resourcing (McOwen *et al*., 2016 Tittensor *et al*., 2014), along with continued updating of the existing indicators, most of which lack any sustained core funding (Juffe-Bignoli *et al*., 2016a, McOwen *et al*., 2016). Many of the existing indicators cannot be disaggregated to show trends in relation to indigenous and local people (leading to calls for including an 'indigenous qualifier' in data collection and SDG indicator development, in order to highlight the inequalities that Indigenous Peoples face across all SDGs (AIPP *et al*., 2015).

A new synthesis of the high-level messages and key findings from different biodiversity-related assessments may be helpful in developing and implementing new targets and indicators for a post-2020 global biodiversity framework (CBD 2018d). New data collection and sharing platforms, and support and capacity-building for data mobilization analysis is needed, particularly for developing nations (Tittensor *et al*., 2014) and non-western data sources (Meyer *et al*., 2015). Scaled-up *in situ* monitoring of biodiversity state, drivers and conservation responses is urgently needed to address the various gaps, particularly in tropical regions (Stephenson *et al*., 2017), and encompassing community and citizen science initiatives (Latombe *et al*., 2017). Appropriate national systems and data platforms for coordinating the collection and dissemination of monitoring data (e.g., 'clearing house mechanisms') would help to address this need, while capacity-building is needed in relation to data collection and analysis. While indicators are probably the most useful and best tool to assess progress, it is unlikely that all of the indicators needed will ever be available. Gaps can also be filled with other sources of information such as published studies and case studies (see sections 3.2, 3.3), or national reports from countries (e.g., CBD National reports) that may help measure progress towards achieving targets.

Other knowledge gaps limit the effectiveness of attempts to formulate and/or implement appropriate policies and responses. In particular, it would useful to review the effectiveness of further policy options, interventions, resource mobilization and the successful use of funding when implementing targets or developing new indicators (CBD 2018d). There is a lack of information on the effectiveness of different area-based conservation mechanisms (protected areas, community reserves, sacred sites etc.), restoration methodologies and indicators to assess progress, and a number of key threats (e.g., from unsustainable exploitation) lack adequate global spatial datasets (Joppa *et al*., 2016). Inadequate monitoring has limited the ability to adapt and adjust policies and their implementation to enhance their effectiveness and to share lessons.

For some of the SDGs, (e.g., Goals 1 and 3), the relationships between nature and achievement of these goals are not well understood, as they are complex, nonlinear, dynamic, context-specific and heavily affected by other anthropogenic mediating factors such as access, policies, governance contexts (see section 6.2), the dominant economic model (see section 6.4 of chapter 6), and demographic factors. Generally, the provision of ecosystem services is widely assumed to contribute to poverty alleviation, particularly in rural areas of developing countries. However, the means by which these contributions are achieved remains unclear (Suich *et al*., 2015; see section 6.3 of chapter 6). There is good evidence on the role that nature plays in supporting the well-being of people, but far less evidence on how (and whether) nature can help people move out of poverty and what changes in nature mean for pathways out of poverty.

Marine biodiversity and ecosystem knowledge vary considerably in quality and extent across geographic regions, habitats, depth and taxonomic groups. It is estimated that 98.7% of the ocean is still largely under sampled, meaning that we lack even the most basic knowledge needed for effective management (Appeltans *et al*., 2016; Figure 3.24). While coastal shelves and slopes in developed nations (e.g., the North Atlantic) are better known (Rice *et al*., 2016), even for these, knowledge is patchy both at temporal and spatial scales. Sampling efforts have been relatively high along coastal ecosystems but are still quite low in the open ocean (>2,000 km from land) even if they have intensified in the last decades (Appeltans *et al*., 2016). Some regions have received considerable attention, but habitat complexity and logistical challenges mean that knowledge is fragmented, and some areas are very poorly known (Alder *et al*., 2016; Appeltans *et al*., 2016; Lindal Jorgensen *et al*., 2016; Miloslavich *et al*., 2016; Ruwa & Rice, 2016). Knowledge of the sea below 1,000 m depth (i.e. almost 99% of the ocean volume), is very limited as this environment is significantly under sampled. A global strategy to assess deep sea ecosystems in a coordinated manner has been recently initiated in anticipation of potentially intensive exploitation of deep-sea resources (Johnson *et al*., 2016).

The best assessed marine species groups are commercial and top predator fish stocks (Campana *et al*., 2016; FAO, 2016; Hazin *et al*., 2016; Pauly & Lam, 2016; Restrepo *et al*., 2016), marine mammals (mainly focused on iconic or threatened species) (Rodrigues *et al*., 2014; Smith *et al*., 2016), seabirds (Croxall *et al*., 2012; Lascelles *et al*., 2016), turtles (Wallace *et al*., 2016), and plankton (Batten *et al*., 2016; Edwards *et al*., 2012), and coastal ecosystems such as coral reefs (Wilkinson *et al*., 2016). However, even within these, few have long-term time series data as, for example, the Continuous Plankton Recorder (80+ years) or the Great Barrier Reef Monitoring Program (20+ years). Only 4% of the 230,000 described marine species have been assessed for the IUCN Red List (IUCN, 2017). Of these, 29% are classified as Data Deficient, and 17% are threatened or extinct, many of which occur in regions of high biodiversity but that are poorly known (Webb & Mindel, 2015). As many of these high-biodiversity regions are also highly threatened by overfishing, habitat loss, pollution, invasive species and the impacts of climate change (Costello *et al*., 2010), it is likely that the number of threatened species will increase as assessments and knowledge of these areas improves (Appeltans *et al*., 2016). Species distributional information is particularly scarce at greater depths **(Figure S3.5)**. All of these knowledge gaps hinder development of effective ecosystem-based management and governance in the marine environment.

Most existing studies on the links between nature and development have focused at an aggregate scale, often only on quantifiable aspects; e.g., income or provisioning services rather than capturing the multidimensional nature of development and nature. More focus has been put on the observation of correlations or relationships, and less on the mechanisms of the links (Roe *et al*., 2014; Suich *et al*., 2015). Thus, most studies are not able to clarify which groups of people benefit (or not) from nature, whether the poor are among these beneficiaries, and which aspects of quality of life are affected by which aspects of nature. Achieving the SDGs will have significant implications for nature (e.g., Goals 7, 8, 9, 11, 12). Choices about how these goals are achieved will have very different consequences for nature, but significant knowledge gaps remain in understanding the positive and negative relationships that nature and its contributions to people may have in achieving targets and vice versa.

Finally, improved information is needed on the role of IPLCs in achieving the Aichi Biodiversity Targets and SDGs, because they hold significant knowledge on the links between nature, sustainable development and quality of life (e.g., Circumpolar Inuit Declaration; Gadamus *et al*., 2015; Ituarte-Lima *et al*., 2018; Singh *et al*., 2018). In addition, capacity-building can help to increase the participation and engagement of IPLCs in sustainable development planning and decision-making at all levels because biodiversity conservation in many locations is under their customary practices or land tenure. Customary institutions, such as local councils, can take the initiative in the recognition, implementation and enforcement of customary laws. However, failure to do so may end up in undermining these laws and result in failure in harnessing all the benefits that may ensue from their implementation.

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Chapter **4.**

PLAUSIBLE FUTURES OF NATURE, ITS CONTRIBUTIONS TO PEOPLE AND THEIR GOOD QUALITY OF LIFE

IPBES GLOBAL ASSESSMENT REPORT ON BIODIVERSITY AND ECOSYSTEM SERVICES
CHAPTER 4. PLAUSIBLE FUTURES OF NATURE, ITS CONTRIBUTIONS TO PEOPLE AND THEIR GOOD QUALITY OF LIFE

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CHAPTER 4

PLAUSIBLE FUTURES OF NATURE, ITS CONTRIBUTIONS TO PEOPLE AND THEIR GOOD QUALITY OF LIFE

EXECUTIVE SUMMARY

Chapter 4 focuses on scenarios and models that explore the impacts of a wide range of plausible future changes in social, economic and institutional drivers on nature, nature's contributions to people (NCP) and good quality of life. The chapter's assessment concentrates on studies published since 2008 that cover large regional to global spatial scales and time periods from the present to 2050, and up to 2100. This framing of the assessment means that this chapter is best suited to help setting the agendas for decision-making at national to international levels by identifying future challenges and providing a compelling case for action. Chapter 4 provides new insights compared to previous assessments by including the most recent scenarios and models, by examining a broad range of global change drivers and their interactions, and by highlighting the impacts on a wide range of indicators of nature, nature's contributions to people and good quality of life. Where possible, results are also interpreted in view of their implications for achieving the Aichi Biodiversity Targets and the Sustainable Development Goals.

This chapter endeavours to provide a balanced perspective on drivers of change and their impacts, but the strong bias in the scenario literature towards climate change impacts on nature limits the scope to which the chapter can provide a comprehensive vision of plausible futures to decision makers. Climate change has been studied far more extensively than other drivers (such as land use change, pollution, use and extraction of natural resources, and invasive alien species), and studies of interactions between drivers, especially more than two drivers, are relatively rare *(well established)* {4.2.1, 4.2.2, 4.2.3, 4.2.4}. Terrestrial systems are studied more extensively than marine systems, with a paucity of studies of freshwater systems (*well established*) {4.2.1.1}. Impacts on biodiversity and ecosystem function have been the focus of much more attention than nature's contributions or good quality of life (78%, 16% and 5% of literature reviewed, respectively; (*well established*) {A1.1}. Among nature's contributions to people, material (such as food production) and regulating contributions (such as carbon dioxide removal from the atmosphere into ecosystems) are more studied than non-material contributions in relation to scenarios (*well established*) {4.3.1}.

The large majority of the studies covered in this chapter is based on scenarios developed in support of climate change assessments (93% of literature reviewed; {4.1.3}, the most recent of which are the Representative greenhouse gas Concentration Pathways (RCPs) and their associated Shared Socio-economic Pathways (SSPs). This has the benefit of providing strong coherence with climate assessments but results in biases in terms of drivers of change and socio-economic processes included in the scenarios. For example, only few of the scenarios assessed in this chapter explore mechanisms leading to social or ecological regime shifts {4.5}. In addition, most scenarios do not explicitly take into account different worldviews and values associated with many non-material nature's contributions to people and, in general, were not designed to address a wide range of Sustainable Development Goals {4.5, Chapter 5}. Nonetheless, this chapter recognizes that the different scenario archetypes hold inherently different worldviews and values that ultimately drive the scenario outcomes {4.1}. Participatory scenarios are one means of including a richer range of processes and values explored, but it is difficult to extrapolate from the local scale of most participatory scenarios to the large regional and global spatial scales that are the focus of this chapter {4.4.2, 4.7}.

1 **Significant changes at all biodiversity levels – from genetic diversity to biomes – are expected to continue under future global changes. Despite projections of some local increases in species richness and ecosystem productivity, the overall effect of global changes on biodiversity is projected to be negative (*well established*). Interactions within and between biodiversity levels can significantly influence future biodiversity responses to global changes (*established but incomplete*).** A substantial fraction of wild species is simulated to be at risk of extinction during the 21st century due to climate change, land use, natural

resource extraction and impact of other direct drivers (*well established*) {4.2.1, 4.2.2, 4.2.3, 4.2.4}. Loss in intraspecific genetic diversity is expected due to the projected decrease in species population sizes and spatial range shifts. Genetic loss should be recognized as a serious threat to future potential for adapting to global change (*established but incomplete*) {4.2.1.2, 4.2.1.3}. Expected species range shifts, local species extinctions, changes in species abundances will lead to disruptions of species relations including disturbance of trophic webs, plant-pollinator and other mutualistic relations (*well established*) {4.2.2, 4.2.3, 4.2.4}, that can cascade through the entire ecosystem. Novel (no-analogue) communities, where species will co-occur in historically unknown combinations, are expected to emerge (*established but incomplete)* {4.2.1.2, 4.2.4.1}. As a consequence, new approaches to conservation are warranted that are designed to adapt to rapid changes in species composition and ensuing conservation challenges. Intraspecific diversity and interactions between different biodiversity levels need to be represented in global models and scenarios to improve future projections of nature {4.2.1.2, 4.2.1.3}.

2 **In marine ecosystems, most scenarios and models point towards a global decrease in ocean production and biodiversity, but the level of impact can vary widely, depending on the drivers, scenarios, and regions considered (*well established*).** All anthropogenic greenhouse gas emission scenarios result in a global increase in sea temperature, ocean acidification, deoxygenation and sea level rise (*well established*) {4.2.2.1}. By the end of the century, these environmental changes are projected to decrease net primary production (by ca. -3.5% under the low greenhouse gas emissions scenario, RCP2.6 and up to -9% in the very high emissions scenario, RCP8.5), and secondary production up to fish (by -3% to -23% under RCP2.6 and RCP8.5, respectively), as well as top predator biomass (*established but incomplete*) {4.2.2.2.1}. Fish populations and catch potential are projected to move poleward due to ocean warming (*well established*) with a mean latitudinal range shift of 15.5 km to 25.6 km per decade to 2050 (under RCP2.6 and RCP8.5, respectively) (*inconclusive*), leading to high extirpation rates of biomass and local species extinctions in the tropics (*well established*) {4.2.2.2.1}. The rapid rate at which sea ice is projected to retreat in polar seas, and the enhanced ocean acidification, imply major changes to be expected in the future for biodiversity and ecosystem function in the Arctic and Southern oceans (*well established*) {4.2.2.2.4}. All components of the food webs will potentially be impacted, from phytoplankton to top predators, and from pelagic to benthic species (*established but incomplete*).

3 **Relative to climate change impacts, published scenarios project that the choice of fisheries management and market regulation measures can have the strongest impacts on the future status of marine fish populations** *(well established)* {4.2.2.3}. In the face of continuous growth of human population that is projected to reach 9.8 billion (± ca. 0.4 billion) people in 2050 combined with rising incomes, the demand for food fish will likely increase (*well established*). Business-as-usual fisheries exploitation is foreseen to increase the proportion of overexploited and collapsed species (*well established*), as well as species impacted by bycatch {4.2.2.3}. Adaptive fisheries management that responds to climate induced changes of fish biomass and spatial distribution could offset the detrimental impacts of climate change on fish biomass and catch in most RCPs (but RCP8.5) (*inconclusive*) {4.2.2.3}.

4 **For marine shelf ecosystems, additional future threats include extreme climatic events, sea level rise and coastal development** which are foreseen to cause increased pollution and species overexploitation but also fragmentation and loss of habitats that directly impact the dynamics of marine biodiversity (*well established*) {4.2.2.2.2, 4.2.2.3}. These impacts could potentially feedback to the climate as coastal wetlands play a major role in carbon burial and sequestration globally (*well established)* {4.2.2.2.2}. In coastal waters, increasing nutrient loads and pollution in combination with sea warming are expected to stimulate eutrophication and increase the extent of oxygen minimum zones with potential detrimental effects on living organisms (*well established*) {4.2.2.3}. Coral reefs are projected to undergo more frequent extreme warming events, with less recovery time in between, declining by a further 70-90% at global warming of 1.5°C, and by more than 99% at 2°C causing massive bleaching episodes with high mortality rates (*well established*) {4.2.2.2.2}.

5 **Concerns about rapidly increasing plastic pollution now match or exceed those for other persistent organic pollutants**. If current production and waste management trends continue, about 12,000 Mt (million tons) of plastic waste will accumulate in the environment by 2050, especially in the ocean which acts as a sink (*established but incomplete*). The harmful effects of plastics have been evidenced at all levels of marine food webs from plankton to top predators but are not yet projected into the future {4.2.2.4.1}.

6 **In freshwater ecosystems, all scenarios and models point towards a decrease in freshwater biodiversity and substantial changes in ecosystems state and functioning, especially in tropical regions (*well established*).** Freshwater ecosystems cover only 0.8% of the world surface area but host almost 8% of the world's species described, making a high contribution to global biodiversity. Given that all scenarios are based on continued growth of human population density until 2050, impacts due to combined anthropogenic drivers on freshwater biodiversity and ecosystems are projected to

increase worldwide, and to be strongest in tropical regions where human population growth and biodiversity are concentrated (*well established*) {4.2.3}. Increases in land area used for urbanization, mining, cropland and intensification of agriculture are projected to boost the risk of pollution and eutrophication of waters, leading to extirpation of local populations, changes in community structure and stability (e.g. algal blooms) (*well established*) {4.2.3.3}, and establishment and spread of pathogens (*established but incomplete*) {4.2.3.3}. Under all scenarios, habitat fragmentation (e.g., damming of rivers) and exploitation are projected to increase the risk of species extinction with potential effects on food web dynamics, especially in tropical regions (*well established*) {4.2.3.4, 4.2.3.6}. These impacts on freshwater flows, biodiversity and ecosystems will likely be exacerbated by climate change, especially under moderate (RCP4.5) and high emissions (RCP6.0, RCP8.5): higher temperatures are projected to generate local population extinctions especially for cold-water adapted species, and species extinctions in semi-arid and Mediterranean regions, since the area extent of these climatic regions will shrink due to projected decrease in precipitation (increase of estimated extinction rates by ca. 18 times in 2090 under the SRES A2 scenario, compared with natural extinction rates without human influence) (*inconclusive*) {4.2.3.2}.

7 In terrestrial ecosystems, scenarios and models point towards a continued decline in global terrestrial biodiversity and regionally highly variable changes in ecosystem state and functioning (*well established*). Land-use change, and invasive alien species will continue to cause biodiversity loss across the globe in the future, with climate change rapidly emerging as an additional driver of loss that is increasing over the coming decades in relative importance across all scenarios (*well established*) {4.2.4}. Although large uncertainties exist regarding the exact magnitude of loss, it is well established that increasing global warming will accelerate species loss {4.2.4}. Already for relatively minor global warming, biodiversity indices are projected to decline (*established but incomplete*) {4.2.4}. Extinction risks are projected to vary between regions from 5% to nearly 25%, depending on whether a region harbours endemic species with small ranges or is projected to experience climate very different from today (*inconclusive*). Substantial climate change driven shifts of biome boundaries, in particular in boreal and sub-arctic regions, and (semi)arid environments are projected for the next decades; warmer and drier climate will reduce productivity (*well established*) {4.2.4.1}. In contrast, rising atmospheric CO_2 concentrations can be beneficial for net primary productivity of ecosystems, and is expected to enhance woody vegetation cover especially in semi-arid regions (*established but incomplete*) {4.2.4.1}. The combined impacts of CO_2 and climate change on biodiversity and ecosystems remain (*unresolved*) {4.2.4.1}.

8 The relative impacts of climate change versus land-use change on biodiversity and ecosystems are context-specific and vary between scenarios, regions, and indicators of biodiversity and ecosystem functioning (*well established*) {4.2.4.2, 4.2.4.3}. Land-use change pressures differ between scenarios, but managed land area continues to increase, with exception of some scenarios exploring sustainability trajectories. Scenarios of large-scale, land-based climate change mitigation rely on large increases of bioenergy crop area or large reforestation or afforestation with potentially detrimental consequences for biodiversity and some ecosystem functioning *(well established)* {4.2.4.2, 4.2.4.3, 4.5.2}. Interactions of land-cover change and future climate change enhance the negative impacts on biodiversity and affect multiple ecosystem functions (*established but incomplete*) {4.2.4.2, 4.2.4.3}. Pressure on biodiversity and ecosystem function from other drivers such as biological invasions will likely be accentuated at global scale, as trade between climatically and environmentally similar regions are projected to increase, and habitats continue to be disturbed (*established but incomplete)*. Overall, the small number of regional to global scale scenario studies that assess pollution or invasive alien species' impacts on nature precludes a robust assessment {4.2.4.4, 4.2.4.5}.

9 Many scenarios project increases in material nature's contributions to people, which are generally accompanied by decreases in regulating and non-material contributions (*established but incomplete*) {3.1, 3.2}. The simulated trade-offs between material vs. regulating and non-material ecosystem services are especially pronounced in scenarios with strong human population growth and per capita consumption (*established but incomplete*) {4.3.4, 4.2.2.3.1, 4.2.4}. Assumptions about population growth and increase in per capita consumption are projected to lead to rising demand for material services, especially food, materials and bioenergy, and are projected to reduce regulating contributions such as provision of clean water, pollination, or ecosystem carbon storage (*well established*) {4.3.2, 4.3.3, 4.5.3, 4.2.2.4, 4.2.2.5, 4.2.3, 4.2.4}. In the long term, substantial decreases in regulating contributions may have detrimental effects on material contributions, for example climate change impacts on all systems will be increased if climate regulation by forests or oceans is weakened (*well established*). The future magnitude of these cascading effects has yet to be determined *(inconclusive). This is because* most scenarios and models do not consider fully the interactions between multiple drivers and multiple ecosystem impacts, and as a consequence cannot quantify important feedbacks {4.3.3, 4.3.4, 4.5.1, 4.5.4}.

10 Scenarios examining trends in nature and nature's contributions to people show significant regional variation (*well established*). The

interconnectedness of the world regions emphasizes the need for decision-making on ocean, freshwater and land management to be informed by considerations of regional trade-offs among nature's contributions to people (*well established*). Future scenarios show that many regions will experience a general decrease of biodiversity and many regulating and non-material ecosystem services, but others will see increases (*well established*) {4.2.2, 4.2.4, 4.3.3}. The degree to which regions differ regarding impacts of global environmental changes depends on the underlying socio-economic scenarios, with climate change being an additional driver (*established but incomplete*) {4.1, 4.2, 4.3}. Scenarios of a world with regional political- and trade-barriers (Regional Competition Scenario) tend to result in the greatest divergence across regions, scenarios that emphasize liberal financial markets (economic optimism and reformed market scenarios) in intermediate levels of disparity, while scenarios that encapsulate aspects of sustainable development (Regional Sustainability and Global Sustainability scenarios) result in more modest differences between regions (*established but incomplete*) {4.3.3, 4.2.4}. For example, an analysis of the impacts of the shared socio-economic pathway (SSP) scenarios indicates that terrestrial biodiversity and regulating contributions will be more heavily impacted in Africa and South America than in other regions of the world, especially in a regional competition scenario and in an economic optimism scenario compared to a global sustainability scenario {4.2.1, 4.2.4.2}.

Irrespective of the underlying socio-economic assumptions, spatial telecoupling (socioeconomic and environmental interactions over distances) implies that increasing future demand for ecosystem services in certain regions will affect supply of services in others. Material contributions, especially food and energy production, play a dominant role in these telecouplings (*well established*) {4.2.4, 4.3.3, 4.5.2}. Material contributions tend to be traded between regions {4.1, 4.2.4.4., 4.2.4.5, 4.5.2, 4.6}, but locally declining biodiversity cannot be replaced by increased biodiversity in a different location {4.2.2-4.2.4}. If tele-couplings are not accounted for in future scenarios, unrealistically overoptimistic responses to a regional political intervention (e.g., land-based climate mitigation, negative emission policies, sustainable fisheries management for local resources and not for imported ones) are assumed, and measures to reduce detrimental side effects not taken (*established but incomplete*) {4.3.3}.

11 Limiting mean global warming to well below 2°C will have large co-benefits for nature and nature's contributions to people in marine, freshwater and terrestrial ecosystems. Land-based climate change mitigation efforts offer opportunities for co-benefits, but if large land areas are required, trade-offs with biodiversity conservation and food and water security goals will need to be addressed in terrestrial and freshwater ecosystems (*well established*). Climate warming and ocean acidification associated with increasing atmospheric CO_2 are already causing damage to marine, freshwater and terrestrial biodiversity (*well established*) {4.2.2, 4.2.3, 4.2.4} which confirms the urgency of meeting the goals of the Paris Climate Agreement. The degree to which marine and land ecosystems will continue to remove CO_2 from the atmosphere, which at present amounts to nearly 50% of anthropogenic CO_2 emissions, is highly uncertain {4.2.2.1, 4.2.4.1}. On land, reduction of deforestation combined with management practices in cropland, pastures and forests can contribute notably to greenhouse gas emissions reductions (*well established*). Recent cost-effective estimates are between ca. 1.5 and 11 Gt CO_2eq a^{-1} over the coming few decades, the undetermined range depending, amongst others, on which types of measures are included {4.5.3}. Along coastlines, a combination of reduced nutrient discharge (mitigating pollution) and space to allow inland wetland migration (adapting to sea level rise), is essential to preserve the capacity of coastal wetlands to sequester carbon (*established but incomplete*) {4.2.2.2.2, 4.2.2.5}.

Regionally, land conversion pressure is large both in scenarios of high population growth and lack of sustainability considerations, and in scenarios requiring land for bioenergy or afforestation and reforestation to mitigate climate change (*established but incomplete*) {4.1, 4.2.4.3}. Recent projections of an annual carbon uptake in 2050 projected for bioenergy pathways (with carbon capture and storage about 0.9-2.2 GtC a^{-1}) and afforestation/reforestation (0.1-1 GtC a^{-1}) are equivalent to an additional one third to three quarters of today's land carbon sink {4.2.4.3}. It remains uncertain whether the required land area would be available for large bioenergy plantations or afforestation/reforestation efforts, where these areas would be located and whether such net carbon uptake rates can be achieved and maintained {4.2.4.3, 4.5.2}. Likewise, detrimental environmental and societal side effects have been projected to arise from strong mitigation scenarios that rely on large area expansion of managed crop and forested land associated with intensification of production (*established but incomplete*) {4.2.4.3, 4.3.2.1, 4.5.2}.

12 Scenarios repeatedly show that changing food consumption patterns and reducing waste and losses in the food system can contribute significantly to mitigating loss of biodiversity and ecosystem services. Human population growth over the coming decades is projected to increase to nearly 9.8 billion (± 0.4 billion) by 2050 and to 11.4 billion (± 1.8 billion) by 2100. As a consequence of the projected population growth, continued urbanisation, and changes in many countries' diets towards increasing per capita animal protein share and processed food, most scenarios foresee increasing crop area, and in some cases pasture area as well. These projected changes in agricultural land area are combined with intensification of land management and continued increases in crop yields, that are projected to have detrimental environmental and biodiversity side effects associated with agricultural intensification (*well established*) {4.2.2.4.2, 4.3.2.1, 4.3.2.2, 4.5.2}. An increasing number of scenarios emphasizes the potential role of consumption as part of the solutions to overcome these challenges, such as shifting diets towards a globally equitable supply of nutritious calories or reducing wastes and losses along the entire chain from crop production to consumers (*well established*) {4.5.4}. Enhancing efficiencies in the food system has large potential to free up land for other uses such as for biodiversity conservation. Studies that explore dietary scenarios of reduced consumption of animal protein estimate that between ca. 10% and 30% of today's area under agriculture may be freed for other purposes, with possible co-benefits in the form of a globally more equitable distribution of animal protein intake by humans and improved health. Reduced greenhouse gas emissions from the land sector, and reduced irrigation water needs are an additional benefit, which will also release pressure on freshwater pollution and biodiversity (*established but incomplete*). Nearly one-quarter of total freshwater used today in food crop production are estimated to be spared if wastes and losses in the food system were minimized (*inconclusive*) {4.3.1, 4.3.2, 4.5.2, 4.5.3}.

13 **Societies and individuals within societies value differently the regulating, material, and non-material contributions from nature that underpin their quality of life (*well established*).** In future scenarios governed by market forces, multiple dimensions of good quality of life are expected to decline. The decline is particularly pronounced for indicators related to livelihood and income security (*established but incomplete*) {4.4.1, 4.4.2}. Market-based and regionally-fragmented scenarios, associated with growth in population and consumption, indicate continuous deterioration of nature to support economic growth, with some regions affected more than others. Without decoupling economic growth from unsustainable extraction and uses, scenarios show continuous decline in nature's contributions to people. Scenarios exploring sustainability or reformed financial market pathways are projected to result in improved good quality of life (*established but incomplete*) {4.4.1, 4.4.2}. In general, the lack of explicit consideration in global scenarios of good quality of life explicitly, and its regionally and socially differentiated nature, impedes robust projections into the future, in particular for non-material aspects. Interactions of future changes in nature, its contributions to people and good quality of life can be better understood and, therefore, potentially better anticipated and managed, when they are evaluated at regional scales as well as the global scale.

Small-scale farming, fishing and other communities, and Indigenous Peoples around the world that depend directly on local environments for food production, especially in low-income countries, are particularly vulnerable to climate-related food insecurity, which raises important equity and fairness issues. Similarly, in coastal regions, decreases in precipitation and fresh water supplies, along with projected increases in sea level, sea surface temperatures and air temperatures, and ocean acidification are projected to have major negative effects on water security for societies. Nature-based livelihoods may become precarious with intensifying future trends in environmental change (*established but incomplete*) {4.4.1, 4.4.2}. Future threats to biodiversity and ecosystem services also constitute imminent challenges to the cultural identity of communities, particularly when faced with environmental degradation (*unresolved*) {4.4.2}.

14 **The role of people's knowledge, values and traditions, and their potential future changes have been barely explored in global scenarios of future socio-economic and environmental change.** A challenge to the assessment of nature's contribution to people and good quality of life under different future scenarios is their socially differentiated nature. People's values and traditions are crucial in shaping the future, yet they are rarely central to scenario exercises (*established but incomplete*) {4.4.1}. Novel methods are beginning to be developed to fully integrate people's worldviews into scenario planning, however transcendental values held by the social groups have so far not been well incorporated. The process of elaborating scenarios with participatory approaches is increasingly taking into account value negotiations around the meaning of good quality of life (*established but incomplete*) {4.4.2}. Consequently, ethical questions emerge regarding how to build scenarios so that local knowledge, particularly that of Indigenous Peoples and Local Communities (IPLCs), are not coopted in ways that may exacerbate processes of their social marginalization.

15 **Different social groups experience change in ecosystem function and services differently so that a given change scenario usually implies winners and losers in terms of the projected impacts on good quality of life** (*established but incomplete*) {4.4.1, 4.4.2, 4.4.3}. People vary in their access to ecosystem services, exposure to disservices, dependence on ecosystems, needs and aspirations. These are further mediated by societal structures and norms as individual characteristics and power relations {4.4.2, 4.4.3}. Many IPLCs are found in protected areas, where dimensions of good quality of life such as food and energy security may trade off with other dimensions of ecosystem functioning. Indirect drivers of change such as climate mitigation policy (e.g., REDD+) may disproportionately impact the possible trajectories towards achieving good quality of life by IPLCs (*unresolved*) {4.4.1}.

Thus, decision-making about environmental management with implications for different bundles of ecosystem services is an intently political process, with often divergent stakeholder interests and power dynamics. Evaluating the implications for the good quality of life of IPLCs under different scenarios of change can benefit from deliberative and participatory approaches that consider a wide range of stakeholder views, and disciplinary perspectives. Such a diversity of perspectives needs to draw on indigenous and local knowledge, to take account of the multiple interacting factors and socially differentiated experiences, vulnerabilities and preferences (*established but incomplete*) {4.4.2, 4.4.3}. A limitation with participatory approaches is the difficulty of imagining future scenarios of changes in the 'demand side' of nature's contributions. So, a group may discuss how changes in a resource might be affected by climate change, but it is often framed in terms of current social conditions. Likewise, participatory approaches are likely to be more successful if the scale of scenarios (e.g., local, regional, global) and stakeholder group perspective can be matched.

16 **Most internationally agreed policy goals and targets for biodiversity are missed by most countries under business-as-usual scenarios because the current patterns and future trends of production and consumption are not environmentally sustainable. Indeed, trajectories of most biodiversity indicators under business-as-usual increasingly deviate from targets over time (*well established*) {sections 2 and 6}.** The achievement of most biodiversity targets therefore requires a steer away from the current socio-economic trajectory and the worldviews and values that underpin it (*well established*). Scenarios that assume increased sustainability show that achieving most SDGs is possible at some point in the future, but this requires substantive and immediate action (*established but incomplete*) {4.6.1}, and the time horizon of the possible achievement of the SDGs is undetermined.

Scenarios and models can support the formulation of future biodiversity targets in terms of concept, phrasing, quantitative elements, and selection of indicators to monitor progress (*established but incomplete*). Scenario and models are also amenable to exploring interactions among targets (*well established*). For example, scenarios have shown that ambitious protected area expansion plans would conflict with agricultural production under business-as-usual assumptions, and that achieving SDGs for both biodiversity and hunger would require a 50-70% increase in land productivity (*inconclusive*) {4.6.1}.

Focusing future quantitative targets for biodiversity on management outcome rather than effort may improve policy implementation and related management decisions. For example, the numeric component of Aichi BiodiversityTarget 11 relates to the global proportion of protected areas. But the aim of protected areas is to achieve the long-term conservation of nature, which suggests to move the focus to the amount of nature that is protected and the effectiveness of protection rather than proportion of area under protection. Scenarios and models have shown that the outcome of a protected area network is determined by its location, connectivity and management, other than its size.

17 **There is a lack of global-scale impact analyses that integrate across natures, nature's contributions to people and good quality of life.** Most scenarios developed for global environmental assessments have explored impacts of humans on ecosystems, such as biodiversity or productivity loss {4.1, 4.2}. The effects of alternative trajectories of socioeconomic development on ecosystems and ecosystem services have been assessed as one-way outcomes, ignoring the possible interactions between natural and socioeconomic systems. A better understanding of feedback mechanisms is needed on many fronts, for instance: in what ways pollution arising from agricultural intensification does impact pollinators and/or water quality, which in turn impact land use and intensification? How do changes in food prices arising from different land uses feed back to land-use decision-making? How is overfishing leading to the depletion of large predatoryfish and development of global markets for alternative species, often their own prey, leading to further collapse of marine resources? To what extent climate change induced sea level rise is decreasing wetland area and is affecting carbon sequestration? (*established but incomplete*) {4.1, 4.3.2.1, 4.5.1-4.5.3, 4.6.1, 4.7.3}. In addition, storylines of socio-economic development that underlie global scenarios consider mostly material aspects of GQL and do not consider other indicators of GQL {4.4.1-4.4.3}. There is a knowledge gap in scenario studies about non-material contributions to people compared to material contributions and regulating contributions, which limits our capacity to understand quantitatively how nature, its contributions to people and good quality of life interact and change in time.

In particular, human decision-making at multiple levels is not well integrated in global scenario modelling tools such as Integrated Assessment Models that focus on economic objectives (*well established*) {4.1, 4.2, 4.5.1, 4.5.2, 4.4.1-4.4.3}. A paradigm shift in scenario design could be achieved by considering, alongside of economic principles, provisioning of multiple ecosystem services and GQL as part of the storyline and human decisions (and subsequent scenario realisation), rather than as an outcome of socio-economic drivers {4.6.1}. For a more robust scientific underpinning of biodiversity and multiple sustainability targets, these non-material aspects need to be explicitly addressed in the scenarios (*unresolved*) {4.6.1}. Such scenarios would facilitate policy-relevant scientific evidence through exploration of trade-offs and co-benefits between targets related to biodiversity and ecosystem services, including the interconnected nature of drivers across regions {4.3.4, 4.5.1}. Participatory Scenario Planning, with stakeholders aligned to the scale of the scenario (e.g., the CBD for global scenarios) would allow for a differentiated assessment of good quality of life across stakeholder groups and highlighting winners and losers across environmental or policy scenarios (*established but incomplete*) {4.4.2}.

18 **Large uncertainties remain in future scenarios and related impact studies at the global scale.** Careful analysis and communication of sources of uncertainty in scenarios and models are vital when using them in support of decision-making (*well established*). Global modelling tools to explore futures of biodiversity and futures of ecosystem state and function are still mostly disconnected and do not consider diversity-function links {4.2, 4.7}. Projected future changes in species ranges, community diversity or ecosystems may be under- or overestimated by most studies because they do not explicitly account for impacts of multiple drivers, adaptive capacity of species and for feedbacks arising from species interactions {*established but incomplete*) {4.2.5, 4.5}. Effectively linking scenarios and models across spatial and temporal scales is methodologically difficult and in early stages of development and use but can make important contributions to decision-making when achieved (*established but incomplete*). However, linking must be done with considerable caution because it creates additional complexity that can make the behaviour of scenarios and models difficult to understand and may introduce important sources of uncertainty {4.5, 4.7}. Substantial efforts are needed to identify uncertainty related to models and scenarios and improve the treatment of uncertainty between and within models {4.2, 4.6, 4.7}. Strong, sustained dialogue between modellers, stakeholders and policymakers are one of the most important keys to overcoming many of the significant challenges to dealing with uncertainty and scales issues when mobilizing scenarios and models for decision-making.

4.1 INTRODUCTION

4.1.1 Context and objectives of the chapter

Rapid biodiversity loss and its adverse consequences for nature, nature's contributions to people and Good quality of life clearly remain as key challenges for the coming decades. Economic inequality, societal polarization and intensifying environmental threats have been identified by the World Economic Forum's *Global Risks Report (GRR) 2017* (WEF, 2017) as the top three challenges for global developments over the next decade or more. For the first time, all five environmental risks in the report (extreme weather; failure of climate change mitigation and adaptation; major biodiversity loss; natural disasters; human-made environmental disasters) were ranked both high-risk and high-likelihood (WEF, 2017). These challenges emphasize the importance of the UN 2030 Agenda and the Sustainable Development Goals (SDGs) and the 2050 Global Vision for Biodiversity to facilitate a sustainable future state for the planet, with a recognition of the connections between humans and ecosystem well-being at their core (Costanza *et al.*, 2016).

This chapter focuses on the assessment of scenarios and models that have been used to explore a wide range of plausible futures of nature, nature's contributions to people (NCP) and good quality of life (GQL), focusing on the current-to-2050 time frame and on continental to global spatial scales. One objective is to alert decision makers to potential undesirable impacts of a broad range of plausible

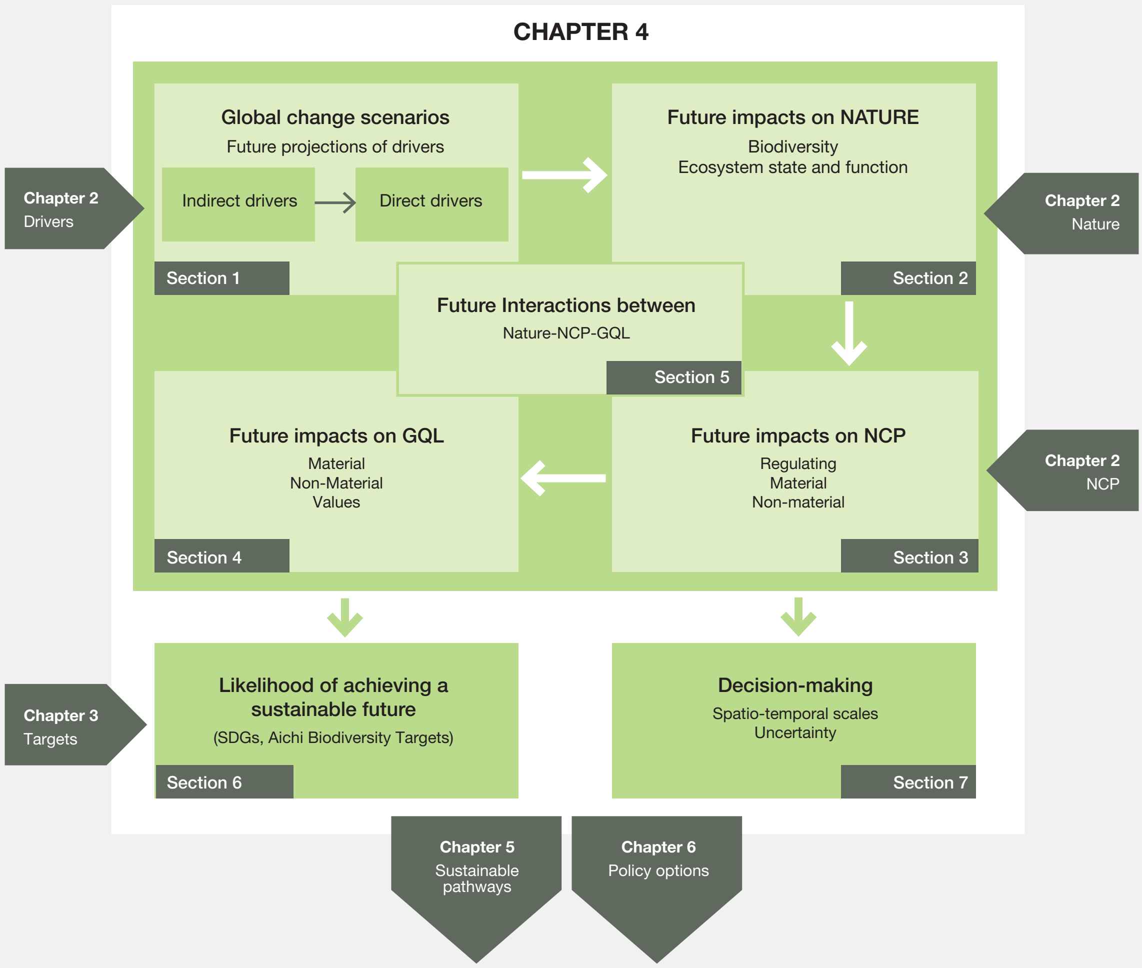


Figure 4 1 1 Scope of Chapter 4 "Plausible futures of nature, its contributions to people and their good quality of life" of the IPBES Global Assessment, content of sections and their relationships, and linkages with the other chapters of the Global Assessment. NCP: nature's contributions to people; GQL: good quality of life.

socio-economic development pathways. A second objective is to highlight development pathways and actions that can be taken to minimize impacts, as well as restore nature and enhance its contributions to people. As is clearly highlighted in Chapters 2 and 3 of this assessment, the context is that pressures, such as resource exploitation and climate change, continue to increase, and most measures of the state of nature and nature's contributions to people continue to decline. This chapter is designed to help understand the conditions under which these trends might accelerate vs. stabilize or even improve over the coming decades.

Scenarios are a means of exploring plausible future trajectories of direct and indirect drivers of environmental change (IPBES, 2016b). Models provide a means to estimate qualitatively or quantitatively the impacts of indirect and direct drivers on nature and nature's contributions to people (IPBES, 2016b). Building upon an analysis of drivers of change presented in chapter 2.1, this chapter starts with an assessment of the key underlying assumptions about drivers in scenarios and a synthesis of the projected trajectories of key direct drivers, such as climate change and land-use change, and indirect drivers, such as human population and economic growth, over the next several decades and places these in the context of current trends (section 4.1; **Figure 4.1.1**, see Chapter 2.1).

Sections 4.2 and 4.3 of this chapter focus on the assessment of a wide range of quantitative models that have been used to project future dynamics of nature and its contributions, and these sections also place these projections in the context of observed trends as well as the current understanding of the mechanisms underlying these trends (see Chapter 2). Models can also be used to evaluate the impacts of changes in nature and its contributions on quality of life, but this has rarely been done (IPBES, 2016b). As such, section 4.4 focuses on the underlying assumptions about quality of life embedded explicitly or implicitly in models and scenarios, as well as making qualitative connections with modeled impacts on nature and its contributions. Projected synergies and trade-offs between nature, NCP and GQL are explored in section 4.5.

Finally, comparisons of scenarios and model outcomes are then made with internationally agreed objectives, such as the Sustainable Development Goals for 2030 and the Convention on Biological Diversity's 2050 Vision, in order to better understand the types of socio-economic development pathways that lead to outcomes that are closest to or furthest from these objectives (section 4.6). This is then put in the broader context of the use of scenarios and models in decision-making (section 4.7), with a focus on the importance of scales and uncertainty in the use of models and scenarios to inform decisions.

Chapter 5 follows by providing a more in-depth analysis of "target-seeking" scenarios designed to evaluate sustainable futures, including evidence regarding sustainable transition pathways, for which specific policy options are discussed in Chapter 6.

4.1.2 Exploratory scenarios

Scenarios can be defined as plausible representations of possible futures for one or more components of a system, or as alternative policy or management options intended to alter the future state of these components (IPBES, 2016b). They provide a useful means of dealing with many distinct possible futures (Cook *et al.,* 2014; Pereira *et al.*, 2010). Policy and decision-making processes rely on estimates of anticipated future socio-economic pathways, and knowledge of the potential outcomes of actions across distinct geographic regions, sectors and social groups. The process of scenario development itself can help to build consensus by integrating the objectives of different stakeholder groups (Priess & Hauck, 2014). This is particularly germane in efforts that seek to integrate the knowledge, perspectives and goals of local stakeholders, particularly Indigenous Peoples and Local Communities (IPLCs), who are frequently marginalized from policy and decision-making processes (IPBES, 2016b; Petheram *et al.*, 2013).

When assessing future impacts on nature, its contribution to people and related good quality of life, there is a need to link the trajectory of direct and indirect drivers to different future scenarios. Exploratory scenarios can be either qualitative, in the form of storylines, or quantitative, in the form of model outputs (van Vliet & Kok, 2015). The main objective of exploratory scenarios is informing stakeholders of the potential impacts of different driver combinations, e.g., a proactive set of actions that may increase the likelihood of social, economic or political targets versus a "business-as usual" scenario that involves no major interventions or paradigm shifts in the organization of functioning of a system. Exploratory scenarios may provide a plurality of plausible alternative and contrasting futures.

Exploratory scenarios for global scale environmental studies and assessments have been developed for a range of UN related assessments, including scenarios developed under the IPCC process, such as the so-called SRES scenarios (Nakicenovic *et al.*, 2000) in the late 1990s, the Representative Concentration Pathways (RCPs) and the recent Shared Socio-economic Pathways (SSPs), as well as scenarios considered for the UNEP Global Environmental Outlook (GEO) (UNEP, 2012) process, Global Biodiversity Outlook (GBO) and the Millennium Ecosystem Assessment (MA, 2005). The Global Scenario Group has also developed a range of contrasting global scenarios (Raskin *et al.*, 2002).

In addition, organizations such as FAO, OECD, IEA and UNESCO have developed several scenarios for specific purposes, such as the OECD Environmental Outlook to 2050 where a trend-based scenario was developed and a large number of policy alternatives were evaluated (OECD, 2012). Several of these scenarios have been evaluated by Integrated Assessment Models (IAMs) to specify and quantify ecological and environmental changes, including climate change, land-use change, vegetation dynamics and water (Kok *et al.*, 2018).

An important advance in the last few years has been to link representative concentration pathways (RCPs) with shared socio-economic pathways (SSPs) (O'Neill *et al.*, 2014) in support of the IPCC process, to inform deliberations under the UN Framework Convention on Climate Change (UNFCCC). Some of these scenarios imply significant mitigation efforts in the land-use sector, including large-scale reforestation and afforestation, or bioenergy crops with implications for both biodiversity and ecosystem services (Riahi *et al.*, 2017).

Existing environmentally relevant scenarios include scenarios that are most often either exploratory (this chapter focus) or target-seeking (Chapter 5) (IPBES, 2016b). In many cases, these scenarios may be appropriate for specific temporal or spatial scales or limited in scope (e.g. relevant to one or a few sectors). They can also be incomplete with regard to quantitative information about nature, NCP and GQL, and thus less useful for the purposes of this IPBES assessment. This is because integrated assessment models that often underpin scenarios of future greenhouse gas emissions, land-use change, or demand for food have a strong economic perspective and do not consider e.g., monetary or non-monetary values of ecosystem services. Issues related to conservation or biodiversity, or feedbacks from changes in ecosystem services to socio-economic decision-making, have typically not been well considered in the wide range of global scenarios that are well established in the climate change scientific communities. Likewise, scenarios of the future of biodiversity typically do not seek to quantify the possible co-benefits related to ecosystem services (Kok *et al.*, 2017; Pereira *et al.*, 2010; Powell & Lenton, 2013). Important gaps remain in scenario development, such as the development of integrated scenarios for areas projected to experience significant impacts and possible regime shifts (e.g. Arctic, semi-arid regions and small islands), and socioeconomic scenarios developed for and in collaboration with Indigenous Peoples and Local Communities (IPLCs) and their associated institutions, values and worldviews (Furgal & Seguin, 2006).

4.1.3 Archetype scenarios

From the many scenarios developed in the last few decades, it is apparent that groups of scenarios have many aspects of their underlying storylines in common and may be considered as "archetype scenarios". Archetypes represent synthetic overviews of a set of assumptions about the configuration and influence of direct and indirect drivers used in scenarios. They vary mainly in the degree of dominance of markets, dominance of globalization, and dominance of policies toward sustainability. Hunt *et al.* (2012) and van Vuuren *et al.* (2012) analysed a large number of local and global scenarios and came to the similar

Box 4 1 1 Scenario archetypes.

(from Hunt *et al.,* 2012; IPBES, 2016b; van Vuuren *et al.*, 2012; see also section 5.2.2 in IPBES, 2018i): description of underlying storylines, and links with indirect and direct drivers.

Economic Optimism. Global developments steered by economic growth result in a strong dominance of international markets with a low degree of regulation. Economic growth is assumed to coincide with low population growth due to a strong drop in fertility levels. Technology development is rapid and there is a partial convergence of income levels across the world. Environmental problems are only dealt with when solutions are of economic interest. The combination of a high economic growth with low population growth leads to high demands of commodities and luxury goods. These demands will however be unequally distributed among regions and within regions. Consequently, energy use and consumption are high. In addition, high technological development in combination with increased global market leads to high yields in agricultural and wood production on the most productive lands. Therefore, pollution and climate change will be relatively high, but land use relatively low. Direct exploitation will continue but also replaced by cultivation of for example fish and livestock. Global trade will increase the risks of invasive species.

Reformed Markets. Similar to the economic optimism scenario family but includes regulation and other policy assumptions to correct market failures with respect to social development, poverty alleviation or the environment. Thereby, relative to the economic optimism archetype, high demands for goods are expected to be more equally distributed and pollution will be lower.

Global Sustainable Development. A globalized world with an increasingly proactive attitude of policymakers and the public at large towards environmental issues and a high level of regulation. Important aspects on the road to sustainability are technological change, strong multi-level governance, behavioural change through education, and a relatively healthy economy. All variations of this archetype are beneficial for biodiversity. This scenario combines a low population growth with moderate economic development, and sustainable production and consumption. Low demands of especially luxury goods are expected, and a shift in diet towards less meat can be expected. Energy use will be low to moderate and fossil fuel use will be reduced, leading to low climate change and low land-use change. Due to environmental policies and sustainable production, pollution will be lower and direct harvesting will partly be replaced by cultivation. The global focus will increase the risk of invasive species

Regional Sustainability. A regionalized world based on an increased concern for environmental and social sustainability. International institutions decline in importance, with a shift toward local and regional decision-making, increasingly influenced by environmentally aware citizens, with a trend toward local self-reliance and stronger communities that focus on welfare, equality, and environmental protection through local solutions. The scenario combines a low economic growth with moderate population growth rates. The demands for goods are low and production focusses on sustainability with low levels of energy use or environmental degradation associated with higher importance for intrinsic and relational values of nature. Low rates of climate change are expected. Supply of agricultural products will be organised with regions with low levels of global trade. A slow technological development and a sub-optimal land use lead to relatively high rates of land-use change. Direct exploitation of natural systems will be within the carrying capacity of natural systems, and risks for invasive species will be relatively low.

Regional Competition. A regionalized world based on economic developments. The market mechanism fails, leading to a growing gap between rich and poor. In turn, this results in increasing problems with crime, violence and terrorism, which eventuates in strong trade and other barriers. The effects on the environment and biodiversity are mixed. Overall, there is a tendency towards increased security, which can either be positive (protect biodiversity) or negative (intensify agricultural production). Particularly in low-income countries, deforestation and loss of natural areas are a risk. In this scenario, due to a lack of global co-operation and trade, a high population growth is expected combined with low economic growth. Thereby, the demand for goods including agricultural products increases, but the demand for luxury, energy intensive goods is relatively low, and thus relatively low climate change is expected. Agricultural supply will be mainly within regions, which, combined with slow technological development, will result in lower productivity and high rate of land-use change. Direct exploitation will continue, low rates of replacement by cultivation are expected. The risk of invasive species will be lower than in the archetypes that focus on globalization.

Business-As-Usual. Assumes that the future can be characterised by a continuation of historical trends, including the implementation of international agreements. Sometimes referred to as a reference scenario, or as a middle-of-the-road scenario. It can also be considered as a less extreme variant of the economic optimism archetype. Business-as-usual is characterized by moderate economic growth, moderate population growth and moderate globalization. Demands are not high nor low, and in combination with moderate technological development, environmental changes will also be moderate.

conclusion that four to six scenario archetypes cover the large range of possible futures **(Box 4.1.1)**.

This chapter makes frequent reference to archetype scenarios because the use of scenario archetypes was also adopted in the IPBES regional assessments. This approach helped to synthesize results across a very broad range of scenario types. Synthesis across regional assessments is hampered by the use of different archetype classifications for each of the regions, which was done in order to match archetypes to regional contexts.

The IPBES methodological assessment on scenarios and models (IPBES, 2016b) adopted the "scenario families", as described in van Vuuren *et al.* (2012), which include the scenario archetypes **(Box 4.1.1)** distinguished by Hunt *et al.* (2012).

The different scenario archetypes describe different visions of the future (de Vries & Petersen, 2009), reflecting different values, guiding principles of society, understanding of good quality of life, approaches to decision-making and distribution of power (among other aspects). These aspects are often included in scenarios as implicit assumptions and have a large impact on the outcomes of the scenarios. For example, some scenario archetypes may prioritize intrinsic values of nature, while others may emphasize instrumental or relational values (Pascual *et al.*, 2017). These differences ultimately affect the different archetypes in various ways. **Table 4.1.1**. shows all these aspects synthesized across the six scenario archetypes. The most common global scale scenarios encountered in the literature can be assigned to these archetypes **(Table 4.1.2)**, with the caveat that individual scenarios do not match all of the characteristics of the archetype defined in **Table 4.1.1** and **Box 4.1.1**.

Analysis of the data sourced from the systematic literature review (Appendix A4.1.1) carried out as part of the background work for this chapter indicates a skewed representation of scenarios between and across the three components nature, NCP and GQL **(Table 4.1.3)**. This skew reflects to some extent the length of time scenarios have been available, but also reflects a bias towards climate change related scenarios. The analysis shows

Table 4 1 1 **Different guiding principles, values, approaches to good quality of life (GQL), distribution of power and decision-making approach across scenario archetypes.**

	Economic optimism	Reformed Markets	Global Sustainable Development	Regional Sustainability	Regional Competition	Business-As-Usual
Guiding Principles	Prosperity based on economic growth	Economic efficiency & sustainability	Global Sustainability	Equity & local sustainability	Individualism and safety concerns	No change
Main value in human-nature relationships	Instrumental / Utility value	Instrumental / Utility value	Intrinsic / Relational	Relational	Instrumental / Utility value	Instrumental / Utility value
Environmental principles	More "efficient" use of nature with new technologies, but protection is not prioritised	Use of nature is regulated with reformed polices	Protecting nature and environmental sustainability	Local sustainable use of nature	Lack of concern/ low priority for nature	Overexploitation of nature with elements of regulation and protection
Social principles	Individualism	Individualism with elements of cooperation	Global cooperation	Cooperation within the community	Individualism in a fragmented world	Individualism with elements of cooperation
Economic principles	Market oriented based on profit maximization	Market regulation based on efficiency & sustainability targets	Market regulation and non-market mechanisms based on global environmental sustainability and equity	Markets oriented to local environmental and quality of life priorities.	Market oriented with trade barriers and growing economic asymmetries / polarisation.	Market oriented with some barriers and some regulation
Approach to good quality of life	Material aspects	Material aspects, health and other GQL components included in international goals (e.g. SDG)	Respect for nature at the global scale is important for GQL	Livelihoods, Social relationships and health	Public security	Material aspects, and other components such as health, public security
Power relations among countries	Large countries powerful	Power imbalance moderated by negotiation	Power balanced by global institutions and collaboration	Decentralized among and within countries	High differences in power among regions	Large countries are powerful, power partially balanced by negotiation, high differences in power among regions
Decision-making processes	Top-down	Top-down	Horizontal / Participatory	Bottom-up / Participatory	Top-down with growing exclusion (marginalisation) of the poorest (most vulnerable) regions & social groups	Top-down
Powerful stakeholders	Private sector	Alliance of governments and private sector	Balance of power among the various stakeholders, global institutions	Communities	National Governments and private sector	Private sector & governments, with participation of NGOs

the available literature is strongly dominated by studies of future trajectories of nature, with considerably fewer studies on NCP and very few studies providing information on GQL. This may reflect the lack of integrated assessment tools available to conduct this type of work quantitatively. This inconsistency of coverage constrained the work in this chapter, and explains the emphasis put on nature (section 4.2).

Table 4 1 2 **Scenarios from earlier global assessments attributed to archetypes or families.**

Source: IPBES, 2016b; van Vuuren *et al.*, 2012.

Source	Economic Optimism	Reformed Markets	Global sustainable development	Regional Sustainability	Regional Competition	Business-As-Usual
SRES	A1F1		B1 (A1T)	B2	A2	B2
GEO3/GEO4	Market first	Policy first	Sustainability first		Security first	
Global scenario group	Conventional world	Policy reform	New sustainability paradigm	Eco-communalism	barbarization	
Millennium Ecosystem Assessment		Global Orchestration	Technogarden	Adapting mosaic	Order from strength	
OECD Environmental Outlook						Trend
Shared Socio-economic Pathways	SSP5		SSP1		SSP3/SSP4	SSP2
Representative Concentration Pathways (RCP)	RCP8.5		RCP 2.6		RCP 6.0	RCP 4.5
Roads from Rio/ fourth Global Biodiversity Outlook		Consumption Change	Global technology	Decentralized Solutions		Trend

Table 4 1 3 **Classification of studies according to scenario represented along a continuum from nature via NCP (nature's contributions to people) to GQL (good quality of life) focused studies.**

The number of papers reported comes from the systematic literature review conducted for this chapter (Appendix A4.1.1).

Scenario	All	Nature	NCP	GQL
RCP8.5	237	198	39	0
RCP6.0	9	9	0	0
RCP4.5	50	41	9	0
RCP2.6	150	144	6	0
A1	6	4	1	1
A1b	119	108	8	3
A1B	4	0	4	0
A1F1	76	76	0	0
A1T	1	0	1	0
A2	200	191	7	2
B1	113	106	6	1
B2	123	117	5	1
SSP1	1	0	1	0
SSP2	13	1	12	0
SSP3	2	1	1	0

Scenario	All	Nature	NCP	GQL
SSP5	1	1	0	0
BAU	23	20	3	0
Global orchestration	13	11	2	0
Order from strength	12	9	3	0
Technogarden	11	10	1	0
Adapting mosaic	8	7	1	0
Consumption change	6	6	0	0
Global Technology	3	0	3	0
Decentralized solutions	1	1	0	0

4.1.4 Projected indirect and direct drivers of change in scenarios

The main indirect drivers of change of nature and its contributions to people, and consequently the quality of life include economic development, demographic trends and factors, technological development, governance and institutions, and various socio-cultural aspects such as worldviews and values. These indirect drivers have multiple impacts on direct drivers of change, which include climate change, land-use change, pollution, direct harvesting, invasive species and disturbance. In each scenario archetype, assumptions on the indirect drivers lead to different combinations of direct drivers **(Box 4.1.1)**.

Drivers are always multiple and interactive, so that one-to-one linkage between particular drivers and specific changes in ecosystems rarely exists. The causal linkage between drivers is often mediated by other factors or a complex combination of multiple factors, thereby complicating the understanding of causality or attempts to establish the contributions by the various drivers to changes in nature, NCP and GQL (see also Bustamante *et al.*, 2018; Elbakidze *et al.*, 2018; Nyingi *et al.*, 2018; Wu *et al.*, 2018). The cumulative effects of multiple stressors may not be additive but may be magnified by their interactions (synergies) and can lead to critical thresholds and transitions of ecological systems (Côté *et al.*, 2016). Cascading impacts of co-occurring stressors are expected to degrade ecosystems faster and more severely (section 4.7 in Bustamante *et al.*, 2018).

4.1.4.1 Indirect Drivers (including consideration of diverse values) in scenarios

Indirect drivers (also referred to as 'underlying causes') operate diffusely by altering and influencing direct drivers as well as other indirect drivers (also see chapter 1 in this report and IPBES, 2016b). They influence human production and consumption patterns with subsequent environmental implications. Economic drivers, including trade and finances, and demographic drivers interact with other indirect drivers such as technology, governance/institutions and social development including equity. Archetype environmental scenarios for this century consider explicit reference to relevant indirect anthropogenic drivers in different combinations, as indicated in **Table 4.1.4**.

Economic development has historically been the key indirect anthropogenic driver of changes in nature, NCP and GQL, across all scales (global, regional, national and local). World GDP (at constant 2010 USD) increased by 6.9 times between 1960 to 2016 (based on Worldbank, 2017). Taking a historical perspective, past and prevailing patterns of production and consumption embodied in global economic trends have generated growing pressures on natural resources, the environment, and ecosystem functions. In all scenarios, world GDP will continue to grow **(Table 4.1.5)**. However, some studies also refer to the plausibility of sustainable de-growth, as a transformative pathway leading to a steady-state at a reduced level of economic output (Schneider *et al.*, 2011).

Economic activities, international trade and financial flows are closely related, particularly in recent decades due to increasing economic globalization. These considerably influence changes in nature, NCP and GQL through various direct and indirect pathways. In turn, these pathways are influenced by a number of policy channels and mechanisms, like trade policies, including incentives (tax exemptions, subsidies) and trade barriers, the dynamics of foreign debt and foreign debt service, flows of foreign direct investments, and monetary policies (dynamic of exchange rates, interest rates).

Demographic trends are a major indirect anthropogenic driver of changes in nature, NCP and GQL, across

Table 4 1 4 **Selected indirect drivers in archetype scenarios.**

Source: Based on Cheung *et al.* (2016: table 6.3); van Vuuren *et al.* (2012).

Selected indirect drivers	Archetype / scenario family					
	Economic Optimism	Reformed Markets	Global sustainable development	Regional Sustainability	Regional Competition	Business-As-Usual
Economic development	Very rapid	Rapid	Ranging from slow to rapid	Medium	Slow	Medium
Trade	Globalisation	Globalisation	Globalisation	Trade barriers	Trade barriers	Weak globalisation
Technological development	Rapid	Rapid	Ranging from medium to rapid	Ranging from slow to rapid	Slow	Medium
Population growth	Low	Low	Low	Medium	High	Medium
Policies & institutions (Governance)	Policies create open markets	Policies reduce market failures	Strong global governance	Local steering	Strong national governments	Mixed

Table 4 1 5 **Economic development (in GDP PPP) for the scenario archetypes.**

Source: MA, 2005; Nakicenovic *et al.*, 2000; OECD, 2012; Raskin *et al.*, 2002; Riahi *et al.*, 2017; UNEP, 2007). Global GDP was approximately 50 trillion $ at purchasing power parity in 2000. GDP PPP: Global Domestic Product based on purchasing power parity.

	GDP PPP in trillion 2000 US$					
	Economic Optimism	Reformed Markets	Global sustainable development	Regional Sustainability	Regional Competition	Business-As-Usual
2050	182-323	181-229	168-251	139-145	106-198	145-241
2100	458-895	427	213-498	310	177-321	310-473

all scales (global, regional, national and local). World population increased by 2.5 times, respectively between 1960 and 2016 (based on the World Bank Database, 2017). Population / demographic drivers consider changes in population size, migration flows, urbanization as well as demographic variables such as population distribution and age structure. Urbanisation driven by growing populations and internal migration acts as an indirect driver of land-use change through various ways, including through linear infrastructures such as transportation networks as well as synergies with other forms of infrastructure development (IPBES, 2016b). By 2050, all archetype scenarios project great increase in human population size, while towards the end of the century, downward trends are projected for the "economic optimism" (SSP5), "global sustainable development" (SSP1), "reformed markets" scenarios **(Table 4.1.2, Figure 4.1.2)**.

Per capita GDP trends combine the impacts of GDP and population growth on environment. Growing per capita GDP has historically implied increasing demand of key natural resources such as food, water and energy with adverse impacts on ecosystems and biodiversity, due to the persistence of unsustainable patterns of production and consumption. Humanity's demand has exceeded the planet's biocapacity for more than 40 years, and the Ecological Footprint shows that 1.6 Earths would be required to meet the demands humanity makes on nature each year, with consumption patterns in high-income countries resulting in disproportional demands on renewable resources, often at the expense of people and nature elsewhere in the world (WWF, 2016).

Technology development can significantly increase the availability of some ecosystem services, and improve the efficiency of provision, management, and allocation

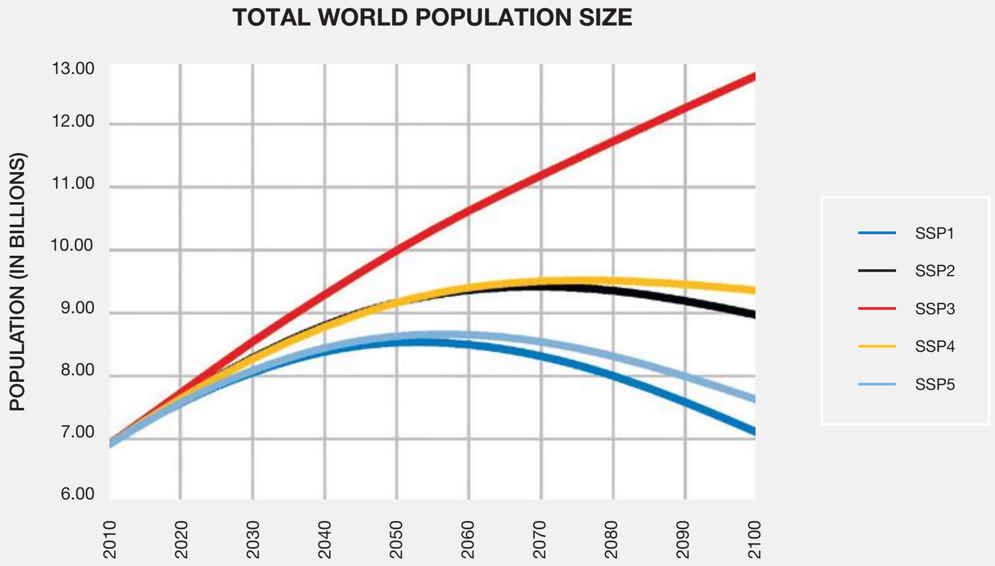


Figure 4 1 2 **Projected changes in world population according to the five Shared Socio-economic Pathways (KC & Lutz, 2017).**

Note: For the narratives of the SSPs, see O'Neill *et al.* (2017).

of different ecosystem services, but it cannot serve as a substitute for all ecosystem services. Technologies associated with agriculture and other land uses have a large impact as drivers of biodiversity and ecosystem change (IPBES, 2016a).

As part of the problem, some technologies can result in increased pressure on ecosystem services through increased natural resource demand as well as lead to unforeseen ecological risks, particularly natural resource intensive technologies, as those associated to agricultural land expansion (e.g., first generation of biofuels when produced unsustainably). In addition, climate change is directly related to the use of fossil-fuel-intensive technologies. As part of the solution, sustainability-oriented technological innovation may contribute to decouple economic growth and the consumption of natural resources through increasing efficiency, resilience and equity (e.g. agroecological food production systems) (IPBES, 2016a; Trace, 2016; Vos & Cruz, 2015).

Governance and institutions play an important role in the management of biodiversity, ecosystem services and ecosystem functions. Weak governance, including corruption, frequently leads to environmental mismanagement as well as the adoption of environmentally unsustainable policies, and growing conflicts (Pichs-Madruga *et al.*, 2016). The lack of recognition of indigenous and local knowledge (ILK) and institutions may also generate adverse consequences for nature, NCP and GQL as well as for Indigenous Peoples and Local Communities (IPLCs).

In addition to governments, new actors and coalitions (e.g. NGOs, researchers, indigenous groups) with different – and sometimes divergent and conflicting – perceptions and values are performing critical roles in environmental decision-making processes.

Social development and culture are critical ingredients of future scenarios on biodiversity, yet there is a lack of attention towards understanding how values, norms, and beliefs affect attitudes and behaviours towards the environment, and their roles in shaping the future and in driving transformation pathways. While there has been advances in methodologies supporting social-ecological analyses, emphasis has been on measurable indicators with less attention to the role of sociocultural values and practices in shaping other indirect drivers of change, and thus future pathways (Pichs-Madruga *et al.*, 2016).

Social inequity is a key concern in many regions, sub-regions, countries and territories. In many cases, poverty conditions correlate with increasing pressures on nature, but globally per capita consumption of natural resources is strongly correlated with affluence. World per capita private consumption, in dollars at constant 2010 prices, rose by 44.5% between 1990 and 2016 (Worldbank, 2017). The emergence of new waves of affluent consumers is projected to significantly increase the demand for already limited natural resources (Myers & Kent, 2003). For this reason, the impact of consumers' purchasing power on the demand of natural resources is receiving growing attention in scenarios. This discussion is very relevant in the context of the global debate on the Sustainable Development Goals (SDGs), multidimensional progress in human development (UNDP, 2016) and their interlinkages with nature and NCP.

4.1.4.2 Direct Drivers

Climate change

By the end of the 21st century, three of four explored Representative Concentration Pathways (RCP; van Vuuren *et al.*, 2011) result in an increase in global average surface temperatures above 1.5°C compared to the present-day reference period 1986-2005 (Stocker *et al.*, 2013). Averaged over years 2046-2065, temperature increases range from (model median) 1.4°C (RCP4.5) to 2.0°C (RCP8.5) above the reference period (1986-2005). Only the RCP2.6 scenario could possibly lead to a below 2°C world, with projected warming above the reference period from 0.3 to 1.7°C averaged over the last two decades of the 21st century, and from 0.4-1.6°C for years 2046-2065. Warming will be larger over land and by far highest in the Arctic. The frequency of extreme hot weather events will increase (Stocker *et al.*, 2013). Precipitation patterns will change in a complex, spatially non-uniform way.

Based on climate modelling done for the IPCC 5th assessment report, and recent work presented in the IPCC special report on 1.5 degrees (IPCC, 2018), limiting warming to 1.5°C above preindustrial levels will require rapid, historically unprecedented mitigation efforts (Millar *et al.*, 2017). Applying a different, statistical modelling approach found below 2°C warming at the end of the 21st century unlikely, and requiring a much accelerated decline in carbon intensity compared to the past decades (Raftery *et al.*, 2017). By 2050, in the RCP2.6 pathway, CO_2 emissions are projected to be lower than they were in 1990. Projected atmospheric concentrations range from ca. 440 ppm (RCP2.6) to ca. 540 ppm (RCP8.5) by 2050 to ca. 420-935 ppm by 2100, but uncertainties are of several tens/hundreds of ppm.

Land-use change

Land-use and land-cover changes have direct and large impacts on the physical environment. They include expansion of crops and pastures, as well as intensification and management changes, mineral and biomass extraction, urbanization and infrastructure expansion (Geist & Lambin, 2002). Eitelberg *et al.* (2015) estimated the global potential for crop area to range from ca. present-day expanse (1500 Mha) to nearly a tripling (5100 Mha), depending on different future socio-economic and governance assumptions. Synthesising projected future crop, pasture and forest areas, Alexander *et al.* (2017c) showed a huge spread in projected future land-use change, and found that this spread depended on the type of scenario, as could be expected, but also was heavily dependent on the type of model used to quantify land use for a given scenario (i.e. the same scenario archetype results in very different land-use change patterns depending on the underlying model's assumptions and structure). Overall, these studies suggest that there remains a high level of uncertainty in future land-use change potential and in scenarios of land-use change.

The five main SSP storylines that have been developed in support of the IPCC can be classified by archetypes **(Table 4.1.2)**, but considerable caution should be exercised when interpreting land-use projections from the SSP storylines as being representative of a particular archetype. For example, the largest declines in global area of forest and other natural land occur in the reference scenarios (also referred to as "marker scenarios") for SSP3, SSP4 and SSP5 (Popp *et al.*, 2017), i.e. scenarios that emphasise competition or free markets. However, the range of variation of the projected change in managed land area by 2100 is nearly as large within SSPs (i.e. variation due to application of different IAMs to the same SSP storyline) as it is between marker scenarios across SSPs (Popp *et al.*, 2017). Given this large variation within SSPs and high uncertainty in land-use projections identified by Alexander *et al.* (2017c), considerable caution must be exercised when making the connection between the underlying assumptions of scenario archetypes **(Tables 4.1.1 and 4.1.4)** and an individual projection of land use by a single Integrated Assessment Model (e.g., **Figure 4.1.3**).

In the wake of the Paris COP21 agreement, terrestrial ecosystems will make crucial contributions to meeting agreed climate mitigation objectives. Achieving the RCP2.6 pathway (or the most recent RCP1.9 pathway, see IPCC, 2018) requires, in nearly all scenarios developed with IAMs, negative emissions through carbon-dioxide removal. The majority of this is generally achieved through reforestation, afforestation and avoided deforestation, as well as bioenergy plantations coupled with carbon capture and storage (Anderson & Peters, 2016; Smith *et al.*, 2016). Depending on how fast fossil fuel emissions decline, substantial negative emissions to balance continued fossil emissions need to be achieved by 2050, or even earlier (Anderson & Peters, 2016) which, if implemented, will have large consequences for terrestrial ecosystems. Recent results indicated that SSPs 1, 2, 4 and 5 might be consistent with low greenhouse gas emissions (i.e., RCP2.6; Kriegler *et al.*, 2014; Popp *et al.*, 2017) (see also examples in **Figure 4.1.3**). Despite the very different assumptions contained in the SSPs (and in the IAMs simulating these) there is consistent projected decline in food crop and pasture area at the end of the 21st century, even though demand for crop and livestock products tend to be larger than today. At the same time, area under bioenergy plantation increases by between ca. 200 Mha (SSP1/AIM) and 1500 Mha (SSP4/GCAM4).

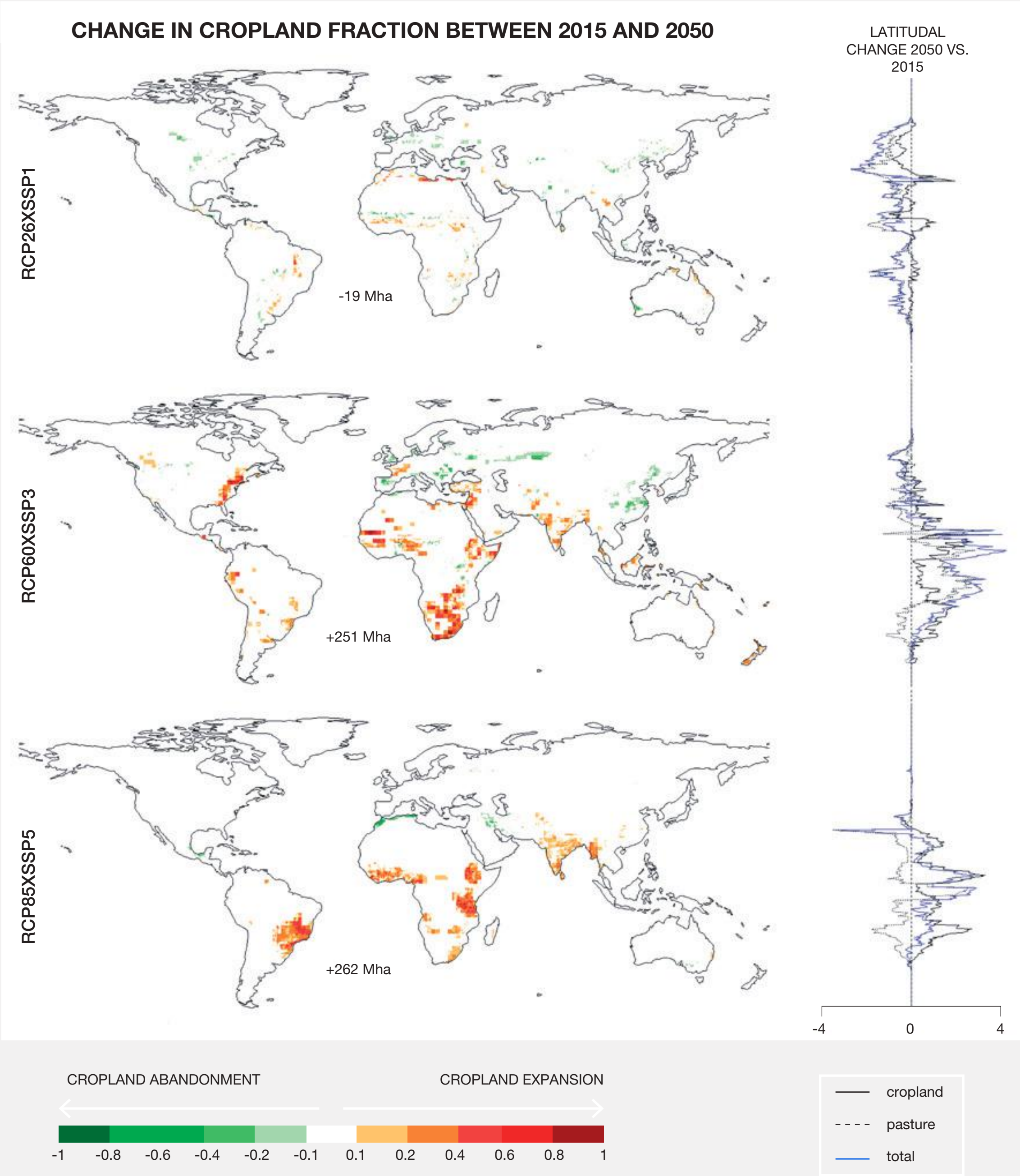


Figure 4 1 3 **Projected changes in cropland area used in the Biodiversity and Ecosystem Services Model Intercomparison Project (BES-SIM, Kim *et al.*, 2018; see box 4.2.5).**

Note that the depicted projections are from a single Integrated Assessment Model per SSP and may not be representative of the range of land-use projections for archetypes to which the SSP is assigned **(Table 4.1.2)**. For instance, trends in agricultural area used by Krause *et al.* (2017, 2018) for their RCP2.6 baseline case were opposite (increasing agricultural area) to the trends seen in the scenario RCP2.6/SSP1 used in BES-SIM. A map with cropland as well as pasture area changes is provided in Appendix 4.1 (Figure A4.1.12).

The intensity of land-use change can be as important as the change in area. In particular, the productivity of croplands is assumed to increase in the future as a result of increased application of technology, including the use of fertilizers, high producing varieties, machinery and pesticides. Intensification has huge impacts on biodiversity in agricultural landscapes, where for example species richness reduces by more than 50% in intensively used croplands, compared to low input systems (e.g., Newbold *et al.*, 2015). Intensification will continue in the coming decades and a recent analysis for the SSP scenarios showed trade-offs between land-use change and intensification **(Table 4.1.6)**.

To meet the demand of a growing and wealthier population, increased agricultural production results from land conversion to cropland in the SSP3/RCP6.0 and SSP5/RCP8.5 scenarios and from intensification in all scenarios, where in SSP3/RCP6.0 scenario a relatively low increase of the yield is assumed.

Pollution

Pollution here refers to solid and chemical waste of various kinds, excluding the gases referenced in the Kyoto and Montreal Protocols. Large increases in waste generation have occurred in the past decades, with a particular challenge for persistent organic pollutants (POPs) and synthetic organic polymers (plastics) which are physically harmful, chemically toxic, and slow to metabolize (see 4.2.2.4.1). Solid waste generation rates depend strongly on urban population growth trends, together with changing standard of living and societal efforts towards waste reduction. On current trends, waste production will attain 11 Mt day^{-1} by 2100, and will continue to rise into the latter half of this century particularly in sub-Saharan Africa (Hoornweg *et al.*, 2013). However, socio-economic pathways could strongly affect waste production trends, with SSP1 stabilising global waste production by about 2070 at roughly 8.5 Mt day^{-1} relative to values of 12 Mt day^{-1} in SSP2 and SSP3 (Hoornweg *et al.*, 2013).

Direct harvesting of natural resources

Scenarios relating to direct harvesting will have complex relationships with distinct socio-economic futures. In terrestrial ecosystems, while an increase in human wealth may reduce direct harvesting of provisioning resources (such as bushmeat), increasing wealth may increase demands for some traditional (e.g. medicinal) and "luxury" (e.g. Rhino horn) resources. On the other hand, marine and freshwater natural resources might undergo increased fishing pressure in the face of rising affluence and continuous growth of human population that is projected to reach 9.8 billion people by 2050 (UNDESA, 2017). Scenarios of governance in fisheries management, human consumption of seafood, improvement of fishing technology (Squires & Vestergaard, 2013) are starting to be integrated into future global scale projections (section 4.2.2.3).

Invasive Alien Species

Invasive alien species (IAS) are those that have been moved by direct human actions beyond their native geographic range, and have established and actively expand geographic range after introduction (Blackburn *et al.*, 2014). The main impacts of socio-economic scenarios on IAS are likely to be through vectors for dispersal (with international trade and long-distance transport being the most important), and economic resources to combat IAS. Higher impacts are thus to be expected under future scenarios of greater global trade with weaker local governance.

Quantification of the impacts of IAS tends to focus on adverse ecological effects (Simberloff *et al.*, 2013), including adverse impacts on ecosystem services. It is thus difficult to develop a fully integrated understanding of positive, neutral and negative impacts, though current consensus strongly suggests overall adverse impacts (Pyšek & Richardson, 2010). For example, invasive plants can cause catastrophic regime shifts and indigenous diversity reduction (Gaertner *et al.*, 2014), such as through N-fixing species increasing N concentrations in nutrient-poor soil (Blackburn *et al.*, 2014), and by increasing fire frequencies and intensities, or even introducing novel fire regimes (Pausas & Keeley, 2014).

Table 4 1 6 **Changes in global cropland area and productivity increase for three SSP scenarios, as analysed in a model comparison study by BES-SIM.**

	SSP1/RCP2.6	SSP3/RCP6.0	SSP5/RCP8.5
Cropland in 2015 in km²	15885409	15885409	15885409
Cropland in 2050 in km²	15696191	18399153	18507559
Cropland area increase 2015-2050 %	-1.2	15.8	16.55
Crop production increase 2015-2050 %	31.7	40.5	58.4
Yield increase 2015-2050 %	33	21	36
Yield increase per year %	0.95	0.61	1.03

Invasive animals may cause extreme indigenous diversity loss particularly if they are predators and invade in islands (Medina *et al.*, 2011).

The number of documented IAS is most probably a significant underestimate of the true number, partly because of inadequate research effort particularly in some developing countries with potentially high IAS densities (McGeoch *et al.*, 2010). The IUCN Red List Index indicates that the adverse impacts of IAS include increased rates of decline in species diversity (McGeoch *et al.*, 2010).

Disturbance

Disturbance is a fundamental driver of biodiversity, and ecosystem structure and function, and may strongly control ecosystem services delivered. Almost all ecosystems experience episodic events like floods, droughts and wildfire. Where disturbance is frequent enough, natural selection both permits nature to adapt, and some species may even become dependent on disturbance, and enhance its frequency (Parr *et al.*, 2014). A prime example is wildfire, which is of global significance in that it is an important factor in determining local to landscape scale ecosystem structure over vast areas of the subtropics and tropics. Without fire, ecosystem structure and function in fire-prone regions may alter their biodiversity, structure and function entirely (Bond *et al.*, 2005). Many plant species are designed to accelerate fire frequency and intensity (Keeley *et al.*, 2011). Disturbance is thus an important tool available in the management of biodiversity, ecosystem structure and function, and the ecosystem services that result (Folke *et al.*, 2004). Disturbance is likely to be most strongly affected by climate (especially in case of fire) as well as socio-economic scenarios. Fire, droughts and flooding would be expected with higher frequency under low future climate change mitigation scenarios. However, for fire it has been argued that changes in human population density, and shifts in urban to rural lifestyles affect future burnt area to the same degree as climate change, through reducing fire spread (Knorr *et al.*, 2016). However, as more people are projected to live in fire-prone areas, potentially detrimental impacts on societies may nonetheless increase (Knorr *et al.*, 2016).

4.1.5 Considering Indigenous Peoples and Local Communities (IPLCs) and indigenous and local knowledge (ILK) in scenarios

The integration of indigenous and local knowledge (ILK) into scenarios developed at the regional and global scales, as well as the assessment of the impacts of scenarios on Indigenous Peoples and Local Communities (IPLCs), have been limited and remain a key challenge in scenario development (Hill *et al.*, 2012; Wohling, 2009). Varying combinations of indirect drivers, and especially government policy, can disproportionately impact IPLCs and their livelihoods. This is particularly significant when considering scenarios as alternative policy or management options intended to alter the future state of these (system) components (IPBES, 2016b). The following examples provide evidence for the potential benefits that could be gained from a better recognition of and respect for ILK and IPLCs in conservation of nature, as well as adaptation to and mitigation of climate change.

Government policies that (i) define agro-industrial plantations as forests, (ii) change property systems, including privatization and land titling over areas of customary tenure, and (iii) incentivize migration to historically low population density areas, undermine ILK that promote biodiversity and human well-being, and traditional land-use practices (Dressler *et al.*, 2017).

Some cases where governments have recognized IPLC land rights and pursued climate mitigation policies, such as through REDD+ projects (Reducing Emissions from Deforestation and Forest Degradation), have led to thus-far successful collaborations and demonstrated that ILK could make significant contributions to future forest and biodiversity conservation (see also review in chapter 6). For instance, the case of GuateCarbon, which incorporates the Association of Forest Producers of Petén (ACOFOP, in northern Guatemala) as full partners alongside government entities and international NGOs, has proved a potentially important model for negotiation, benefit sharing, and monitoring, reporting, and verification that respects local land-use practices and values (Hodgdon *et al.*, 2013). Positive livelihood outcomes have accompanied a pattern of strong forest protection in areas with community-led management here.

Studies suggest that policy scenarios such as protected area designation – including territorial recognition for IPLCs – could play a significant role in avoiding future deforestation, such as in the Amazon, despite continued pressures to downgrade, downsize, and degazette protected areas (PADDD) for infrastructure development and more intensive land uses (Forrest *et al.*, 2015; Soares-Filho *et al.*, 2010). For example, a recent Brazilian moratorium on mega-dams – long demanded by indigenous groups on ecological and spiritual grounds – could enhance ecosystem protection, especially if accompanied by increased support for forest groups (Branford, 2018), despite continuing plans for inter-modal transport projects essentially promoting agro-industry and colonization (Molina *et al.*, 2015). While the Brazilian Amazon has served as an important testing ground for recognizing the importance of ILK in forest management and for REDD+, the continued discounting of ILK systems in broader land-use policy throws doubt on the long-term viability of such participative initiatives (Cromberg *et al.*, 2014; Vitel *et al.*, 2013). Specific major drivers vary by country and by region, but global demand for basic commodities and national enabling environments for investment in forest-rich countries will likely continue to contribute to terrestrial emissions and biodiversity loss – including through incursions on IPLCs' traditional lands and the attendant loss of ILK. Thus, even where REDD+ and conservation initiatives have tried to ensure community participation, they achieve variable success, in part because they often fail to address the strongest indirect drivers of losses of forests, biodiversity and ecosystem services (Angelsen *et al.*, 2017).

Notwithstanding these limits, the long period of negotiation over the program internationally and nationally, in addition to a pivot away from market-based approaches implementation, has provided IPLCs with opportunities to insert their priorities (tenure security, Free, Prior and Informed Consent, social services) into the debate (Angelsen *et al.*, 2017; Van Dam, 2011). Increasing rates of recognition of IPLCs' rights to inhabit and manage their lands alongside new sources of dedicated funding (such as the UNFCCC's Green Climate Fund) could suggest stronger outcomes for avoided deforestation and ecosystem health.

4.2 PLAUSIBLE FUTURES FOR NATURE

4.2.1 Impacts of future global changes on biodiversity: feedbacks and adaptation capacity

4.2.1.1 Projected negative changes at all levels of biodiversity

The scientific community has focused on climate change as a major driver of concern in exploring possible futures for nature **(Table 4.2.1)**. Based on our systematic literature review (Appendix A4.1.1), 88% of the global scenario literature addressed climate change impacts on nature, followed by 8% and 2% of the papers addressing land-use change and natural resource extraction, respectively. A vast majority of the papers addressed single drivers, as few integrated models are able to represent combination of drivers and interactions are more complex to implement (IPBES, 2016b). Of all the scenarios exploring climate change impacts, only 18% were combined with other direct drivers of change such as land use or natural resource extraction.

Table 4 2 1 **Major drivers represented in global change scenarios addressing impacts on nature at global scale, across terrestrial, freshwater and marine ecosystems.**

The number of scenarios published is reported, and in parentheses, the number of scientific papers from the Chapter 4 literature database (Appendix A4.1.1). Scenarios addressed single drivers (purple cells) or combination of drivers.

	Climate change	Invasive alien species	Land-use change	Natural resource extraction	Pollution	Others
Climate change	569(270)	4(3)	104(36)	12(6)	8(4)	11(8)
Invasive alien species		10(2)				
Land-use change			45(19)	7(4)	4(2)	1(1)
Natural resource extraction				16(7)	1(1)	
Pollution					1(1)	1(1)
Others						27(8)

Most scenarios of biodiversity change are terrestrial or marine, while far fewer exist for freshwater (**Figure 4.2.1**; IPBES, 2016b). Therefore, most evidence provided in section 4.2.3 for freshwater biomes is based on local and regional studies. Overall, relatively few metrics of biodiversity and ecosystem function have been explored deeply enough to draw strong conclusions about their interactions in a globally changing environment.

The systematic literature review indicates that the effects of global environmental changes on biodiversity are mostly projected to be negative **(Figure 4.2.1)** and embrace all biodiversity levels – from genetic diversity to biomes (Bellard *et al.*, 2012; **Box 4.2.1**). Marine systems are projected to be generally more negatively impacted by global change drivers than terrestrial systems **(Figure 4.2.1)**. For example, projected changes in species biomass or abundance cover the spectrum of negative to positive trends in terrestrial systems (see evidence provided in sections 4.2.4.1 to 4.2.4.4), but negative trends stand out in marine systems (see section 4.2.2). There are a few metrics, such as terrestrial C pools or organisms' growth, where positive trends are the most common response in the literature (see 4.2.4.1). In case of C-pools this reflects chiefly the impact of CO_2 on photosynthesis and growth, which in some models outpace the impacts of warming. In boreal and temperate regions, climate change was also shown to possibly have positive effects on organisms' growth, e.g., plant growth (Pretzsch *et al.*, 2014). All other metrics of biodiversity and ecosystem function are dominated by projected neutral or negative trends in response to projected global change drivers. Negative trends are particularly dominant for indicators of production, reproduction success, terrestrial species richness and extinction, marine species biomass and abundance, and the area and quality of marine habitats.

Figure 4 2 1 **Future trends of selected indicators in marine A, terrestrial B and freshwater ecosystems C, based on global scale scenarios referenced in the literature database (Appendix A4.1.1), all drivers combined.**

The results are extracted from scenarios with increasing pressures from direct drivers (all climate change scenarios and business-as-usual scenarios for resource exploitation, land-use change and pollution). The selected scenarios were at global scale. Regional/local scale scenarios were not referenced in the literature database. Colours code the projected trends in the indicators. N=the number of trends reported and in parentheses the number of papers.

A substantial fraction of wild species is predicted to be at risk of extinction during the 21st century due to climate change, land use and impact of other direct drivers (Bellard *et al.*, 2012; Pimm *et al.*, 2014; Settele *et al.*, 2014; see sections 4.2.2-4.2.4). In a recent review of published future global extinction risk, Urban (2015) found that extinction risk is projected to increase from 2.8% at present to 5.2% at the international policy target of a 2°C post-industrial rise, to 8.5% if the Earth warms to 3°C, and to 16% in a high greenhouse gas emissions scenario (RCP 8.5; 4.3°C rise). Extinctions might not occur immediately but after substantial delay called because when a population has been reduced to very small numbers, it has a high risk to go extinct at some point in the future (referred to as «extinction debt»). This means that long-term effects of global change can be much more severe than short term impacts (Cronk *et al.*, 2016; Dullinger *et al.*, 2012; Fordham *et al.*, 2016; Hylander & Ehrlén, 2013).

Notwithstanding a majority of expected negative impacts of future climate change on biodiversity, **Figure 4.2.1** suggests the potential for some positive effects in species distributions areas and species richness. General poleward movement of marine and terrestrial species and upward movement of terrestrial mountain species may lead to increase in local species richness in high latitudes and in mountainous regions, while the opposite is projected in the tropics and flat landscapes (Gilg *et al.*, 2012; Jones & Cheung, 2015; Settele *et al.*, 2014; Thuiller *et al.*, 2014).

Global scale scenarios can mask the spatial heterogeneity of projected biodiversity response at finer scales (Urban, 2015; Vellend *et al.*, 2017). For example, the highest species extinction risk due to climate and land-use changes is projected in the tropics and polar regions as well as in top mountain habitats because of projected "novel" climates in tropics that these regions have never experienced in the past (Mora *et al.*, 2013a), narrow physiological tolerances of tropical and polar species, expected disappearance of polar and top-mountain habitats (Deutsch *et al.*, 2008; Gilg *et al.,* 2012; Mora *et al.*, 2013a; Pörtner *et al.*, 2014; Settele *et al.*, 2014) and the highest risk of conversion of ecosystems to crops and biofuel in the tropics (Kehoe *et al.*, 2017; Newbold *et al.*, 2015). Biodiversity hotspots are also projected as subject to high species extinction (Bellard *et al.*, 2014; see 4.2.2, 4.2.3, 4.2.4).

To account for the spatial differentiation of global changes impacts on nature, the following sections 4.2.2, 4.2.3, and 4.2.4 cover the outcomes of the literature database analysis (Appendix A4.1.1), but also include detailed examination of key studies and specific biomes (IPBES units of analysis). The major drivers of change and the primary impacts differ depending on the biome considered **(Figure 4.2.2)**, and therefore need to be addressed by specific, and sometimes local, adaptation and mitigation policies.

4.2.1.2 Future biodiversity adaptation and reorganisation

Species can respond to environmental changes in many different ways that are not mutually exclusive. In response to changes in climate, species can adapt to new conditions, they can shift their geographical distribution following optimal environmental gradients or can go locally extinct.

A large number of scenarios explore ***species distribution shifts***. Terrestrial species may respond to climate changes by shifting their latitudinal and elevation ranges. Marine species may respond by shifting their latitudinal and depth ranges. Models predict latitudinal range shifts for plant and animal species of hundreds of km over the next century as well as significant range contraction and fragmentation (Leadley *et al.*, 2010; Markovic *et al.*, 2014; Meller *et al.*, 2015; Rondinini & Visconti, 2015; Warren *et al.*, 2013). Comparisons of projected climate velocity (the rate of movement of the climate across a landscape) and species displacement rates across landscapes showed that many terrestrial species (e.g., plants, amphibians, and some small mammals) will be unable to move fast enough to track suitable climates under medium and high rates of climate change (i.e. RCP4.5, RCP6.0, and RCP8.5 scenarios). Most species will be able to track climate only under the lowest rates of climate change (RCP2.6) (Settele *et al.*, 2014). Natural geographical barriers (Burrows *et al.*, 2014) and human-made habitat disruptions are predicted as important factors limiting movement of species ranges (Meier *et al.*, 2012; Schloss *et al.*, 2012).

Species adaptation to novel conditions is likely to mitigate the predicted impacts of global changes (Hoffmann & Sgrò, 2011; Lavergne *et al.*, 2010; Neaves *et al.*, 2015; Pauls *et al.*, 2013; Skelly *et al.*, 2007). Models that ignore adaptation may overestimate extinction probabilities. For example, the inclusion of local adaptations due to phenotypic plasticity and microevolution in models of terrestrial carnivore and ungulate species decreases the expected decline in population abundance by 2050, from 31–34% to 18% (Visconti *et al.*, 2016; see **Box 4.2.1**)

Intraspecific diversity of behavioral, phenological, physiological and morphological traits allows populations and species to survive under rapid climate change through standing genetic variation (GD1 in **Box 4.2.1**), and provides material for selection in new conditions (Alfaro *et al.*, 2014; Hof *et al.*, 2011; Jump *et al.*, 2009). On the one hand, incorporating intraspecific variation in species models increases the likelihood of their survival as shown for several tree species (Benito Garzón *et al.*, 2011; Morin & Thuiller, 2009; Oney *et al.*, 2013). On the other hand, projections that do not consider probable loss of intraspecific diversity can underestimate future negative effects on biodiversity. The loss of genetic diversity is projected for a number of

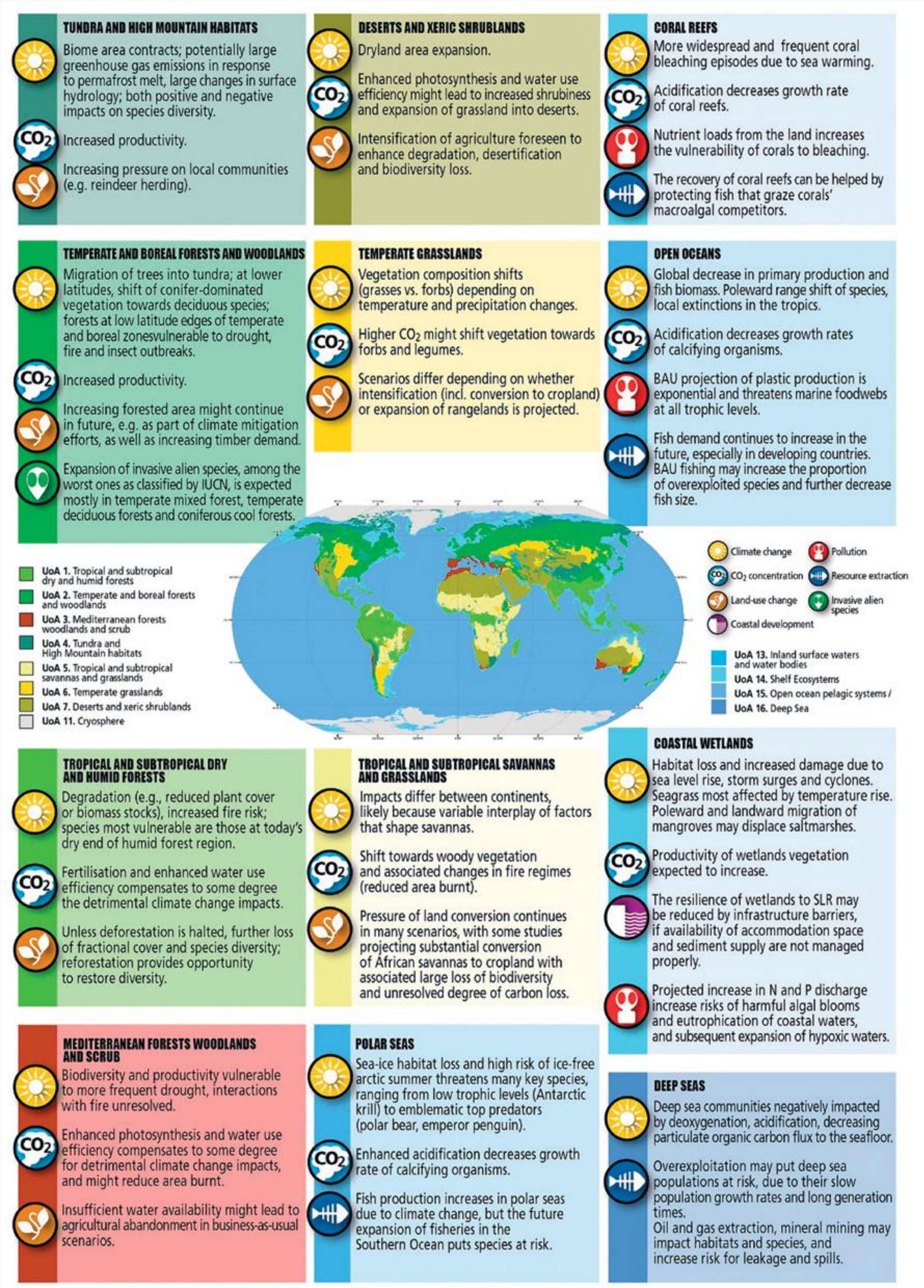


Figure 4 2 2 **Examples of future projected impacts of major drivers of change on nature (supporting evidence in sections 2.2 and 2.4 of the chapter, and Table A4.2.1 in Appendix 4.2).**

Examples are given for IPBES terrestrial and marine units of analysis (UoA).

species belonging to very different terrestrial and aquatic taxa and thus, should be recognized as a serious threat to future biodiversity rescue (Bálint *et al.*, 2011; Jump *et al.*, 2009; Neaves *et al.*, 2015; Pauls *et al.*, 2013).

Phenotypic plasticity helps to reduce the risk of species extinction (GD2 in **Box 4.2.1**) allowing a rapid (within individual's lifetime) adjustment of populations to novel conditions whereas evolutionary responses require several generations (Chevin *et al.*, 2010). Incorporating phenotypic plasticity in models predicting future species' distributions reduced the extinction risk in southern populations of several species (Benito Garzón *et al.*, 2011; Morin & Thuiller, 2009).

Rapid adaptive evolution (GD3 in **Box 4.2.1**) occurring at similar time scale as global environmental change has the potential for "evolutionary rescue", i.e. population survival *in situ* due to ongoing selection of standing genetic variations as well as relatively slower selection of new mutations (Gonzalez *et al.*, 2013; Hendry *et al.*, 2011; Hoffmann & Sgrò, 2011; Settele *et al.*, 2014). However, evolutionary responses may be too slow for species with low capacity for adaptive evolution, especially under large-scale and rapid environmental changes (Gienapp *et al.*, 2012; Jump *et al.*, 2006).

Adaptation can cascade to entire communities or ecosystems, thus maintaining community properties beyond the level of change in the driver. However, adaptive capacity is not unlimited and so even evolving systems can eventually switch to a new state if a change in a driver is too severe or too rapid. Return to the original system state when change pressure is removed to the original state can be harder than would have been the case without evolution, due to the depletion of the genetic variation **(Figure 4.2.3)**.

Along with the vital importance of preserving the short-term adaptive capacity of biodiversity, the necessity of *long-term maintenance of further evolutionary* processes generating biodiversity and potential future ecosystem services was recognized as a key goal that requires preservation of evolutionary heritage and phylogenetic diversity of the Tree of Life (Faith, 2015; Faith *et al.*, 2010; Forest *et al.*, 2007; Mace & Purvis, 2008).

Reorganization of ecological communities and novel communities: Substantial changes in *species composition and biotic interactions* are expected due to shifts in species distribution (S1 in **Box 4.2.1**), local species extinctions, alterations of species abundance, functioning and phenology (S2 in **Box 4.2.1**). Projected changes in species composition can lead to disruptions of food webs and mutualistic relationships, increased prevalence of pests and pathogens, introductions of alien species, biotic homogenization and loss of biological uniqueness of communities (Blois *et al.*, 2013; Buisson *et al.*, 2013; Thuiller *et al.*, 2014).

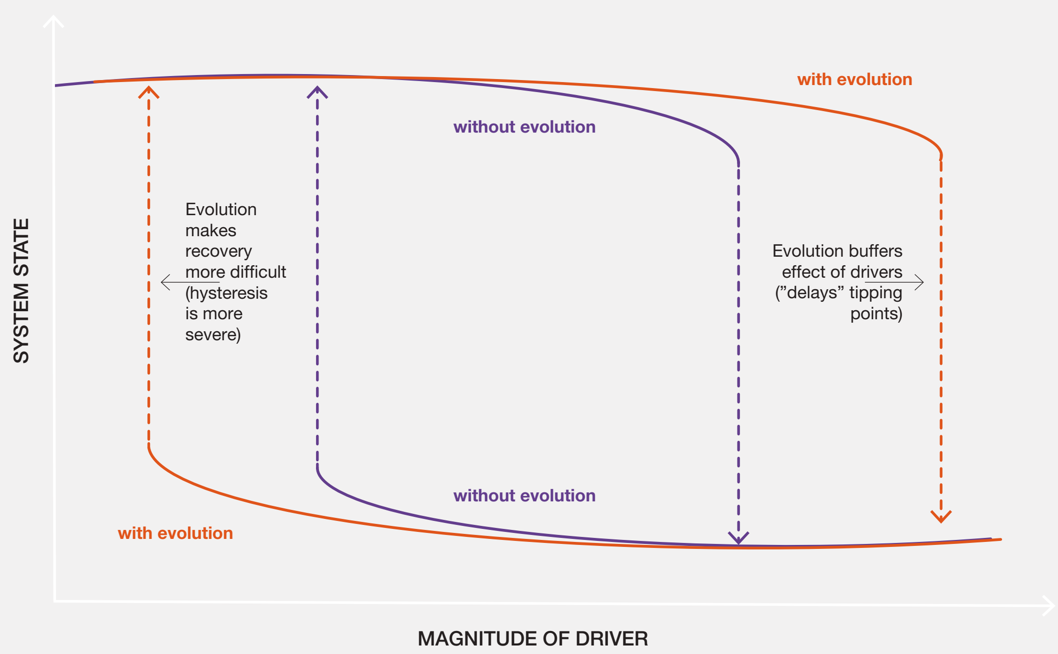


Figure 4.2.3 Potential role of evolution (more generally, "adaptive capacity") in mediating tipping points, alternative stable states, and hysteresis.

Novel (no-analog) communities, in which species will co-occur in historically unknown combinations, are expected to emerge (Ordonez *et al.*, 2016; Radeloff *et al.*, 2015; Williams & Jackson, 2007). Novel communities are expected to become increasingly homogeneous and shifted towards smaller size species and generalists with broader ecological niches (Blois *et al.*, 2013; Lurgi *et al.*, 2012). Novel interactions can strongly affect species fitness because species will lack a long coevolutionary history in new conditions (Gilman *et al.*, 2010; see also Appendix 4.2).

4.2.1.3 The importance of feedbacks between hierarchical levels of biodiversity

Some well described feedbacks between different hierarchical levels and facets of biodiversity are self-reinforcing and could likely amplify negative effects of global changes on biodiversity (Brook *et al.*, 2008). Integration of processes acting at different organizational biodiversity levels is essential for future predictions of global change impacts on nature (Mouquet *et al.*, 2015; Thuiller *et al.*, 2013).

The feedback between population size and genetic diversity (S4 in **Box 4.2.1**) is known as an extinction vortex (Frankham *et al.*, 2014) because the reduction in population size leads to the loss of genetic diversity which in turn, leads to decrease in population fitness and adaptability and further reduction in population size. The *feedback between species' range and genetic diversity* (S5 in **Box 4.2.1**) means that the contraction and fragmentation of species ranges are expected to cause genetic loss through decrease in effective population size and extinction of genetic lineages as well as extinction of local populations with unique genetic characteristics (Bálint *et al.*, 2011; Pauls *et al.*, 2013). Genetic loss, in turn, may decrease species adaptability and migration capacity. The *feedback between species composition and genetic diversity* (SD3 in **Box 4.2.1**) means that changes in species composition alter the selection pressure affecting genetic diversity. For example, reduction in pollinator abundance could lead to selection favoring self-fertilization in plant populations, leading to a decrease in genetic diversity (Neaves *et al.*, 2015). Introductions of alien species may result in hybridization, out-breeding depression and decrease in genetic diversity of native species. However, hybridization may also facilitate adaptation to novel environments (Hoffmann & Sgrò, 2011). Changes in genetic diversity, in turn, contribute to further disturbance of species relationships.

The *feedback between species composition and single species extinctions* (SD4 in **Box 4.2.1**) make changes in species composition and single-species extinctions modify the web of interactions at the community level and lead to cascading and catastrophic co-extinctions called "chains of extinction" (Bellard *et al.*, 2012; Brook *et al.*, 2008). The loss of key species as well as invasions and proliferation of pests and pathogens can have the most drastic effects. Failing to account for changes in biotic interactions could cause models to under- or overestimate extinction risks (Gilman *et al.*, 2010). The *feedback between species composition and species' capacity to track climate change* (SD5 in **Box 4.2.1**) implies that interspecific interactions can modulate the outcome of species range shifts. Mutualistic interactions, such as plant-pollinator relations, may fail in tracking fast environmental change (Lavergne *et al.*, 2010). Competition and predation can both hamper and facilitate range shifting (Holt & Barfield, 2009; Svenning *et al.*, 2014). Interactions can slow climate tracking and produce more extinctions than predicted by models assuming no interactions (Urban *et al.*, 2013). Moreover, interspecific interactions can modulate the direction of species range shifts, for example, species may shift downslope due to competitive release at the lower margin of species distribution (Lenoir *et al.*, 2010). Changes in species distribution, in turn, contribute to further changes of species composition. The *feedback between landscape homogenization and species extinctions* (ED2 in **Box 4.2.1**) involves that predicted biotic homogenization and loss of biological uniqueness of communities within a region (Blois *et al.*, 2013; Buisson *et al.*, 2013; Thuiller *et al.*, 2014) can synchronize local biological responses to disturbance across individual communities and thus, compromise the potential for landscape- and regional-level disturbance buffering (Olden, 2006). Taxonomic homogenization of communities can reduce resistance of a landscape to future invasions (Olden, 2006). As a result, local extinctions of native species and invasions of alien species should be expected that, in turn, will contribute to further biotic homogenization (for details, see Appendix 4.2).

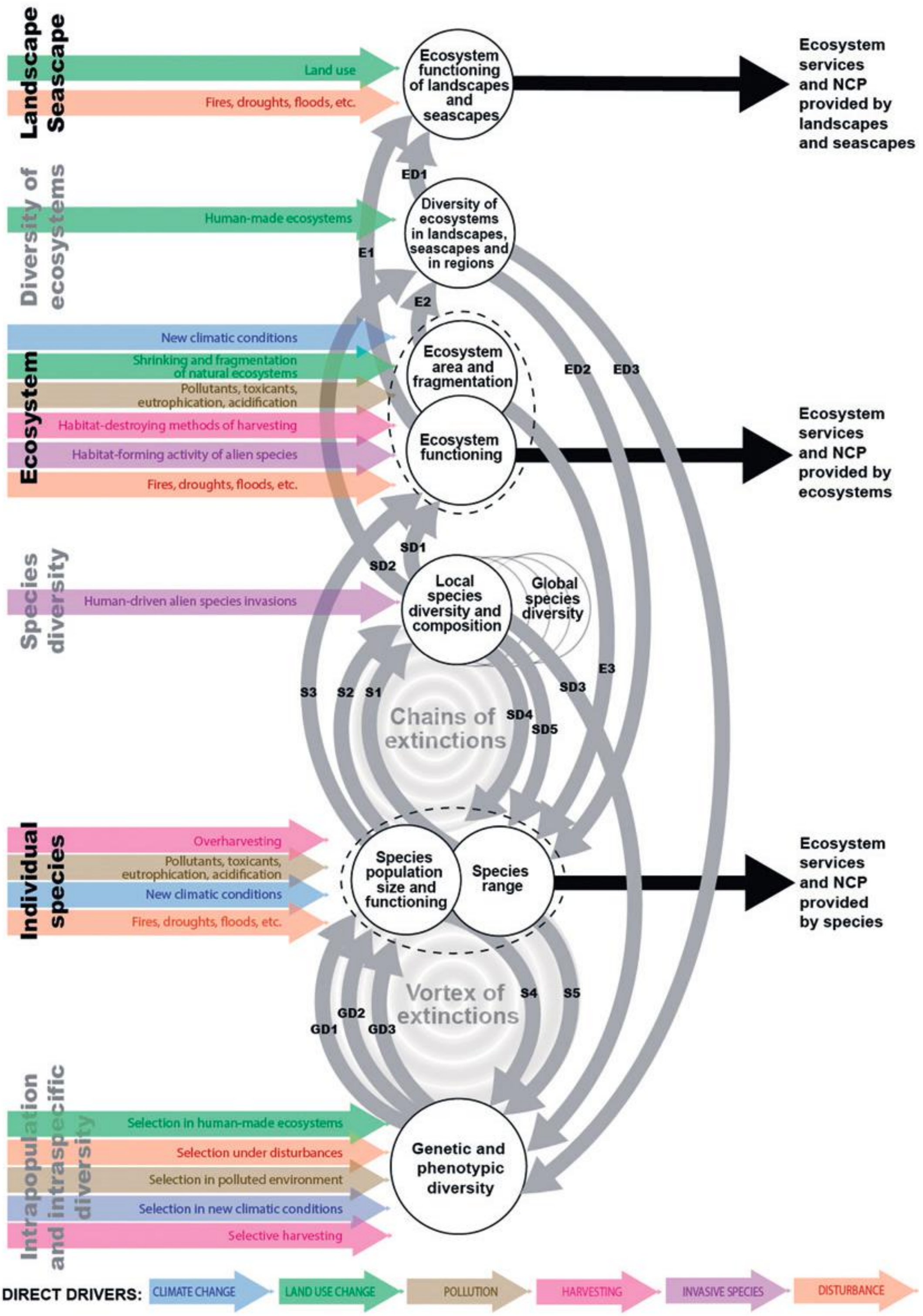
4.2.2 Marine ecosystems

4.2.2.1 Global state and function of marine ecosystems and future drivers of change

The ocean is central to regulating the Earth's climate. The ocean absorbs around 25% of the anthropogenic emissions of CO_2 (Le Quéré *et al.*, 2016), leading to ocean acidification with a decrease in surface seawater pH of 0.1 units since the beginning of the industrial era (Orr *et al.*, 2005). The ocean absorbs 93% of the Earth's excess heat energy, resulting in warming of 0.11°C per decade in the upper 75m of the ocean between 1971 and 2010 (Rhein *et al.*, 2013). ***Oceans are essential to life and provide major services to human societies.*** Marine phytoplankton produce about half of the global O2 (Pörtner *et al.*, 2014). The ocean supports fisheries and aquaculture activities and produced on average 104.3 million tons

Box 4 2 1 The main interrelations and feedbacks between hierarchical levels that are important for the future of biodiversity.

Direct drivers of global change affect all levels of biodiversity, either directly (coloured arrows) or indirectly through feedbacks (grey arrows). Even one-way interactions are important for biodiversity response, while self-reinforcing feedbacks can potentially significantly increase expected negative effects of global change drivers (for details, see Appendix 4.2).



Effects of changes in genetic and phenotypic diversity
GD1 – adaptation of populations to new conditions through standing genetic and phenotypic variations
GD2 – adaptation of populations due to phenotypic plasticity
GD3 – adaptive evolution, "evolutionary rescue" of populations and species

Effects of changes in functioning, population size and range of individual species
S1 – changes in local species composition due to alteration of species range (shift, change in area, fragmentation)
S2 – changes in local species composition due to local species extinctions and alteration of species abundance and functioning (including changes in phenology)
S3 – changes in ecosystem structure and functioning due to changes in key species abundance and functioning
S4 – changes in genetic diversity due to changes in population size
S5 – changes in genetic diversity due of alteration in species range (shift, change in area, fragmentation) and dispersal ability

Effects of changes in local species diversity, species composition and interspecific relations
SD1 – weakening and destabilization of ecosystem functioning due to loss of local species diversity
SD2 – biotic homogenization as a result of species shift, local species extinctions and invasions
SD3 – changes in selection pressure because of alteration of species composition and interspecific relations (including effects of alien species invasions)
SD4 – species extinctions as a result of cascading effects of alteration of species composition
SD5 – impact of alteration of species composition on species capacity to track climate change

Effects of changes in structure and functioning of ecosystems
E1 – the contribution of individual ecosystems to the total landscape/seascape ecosystem functioning
E2 – disappearance of the most vulnerable ecosystems in landscapes/seascapes and regions
E3 – reduction of species population size, reduction and fragmentation of species' ranges and disruption of population structure because of habitat loss and fragmentation

Effects of changes in diversity of ecosystems, heterogeneity of landscapes and seascapes
ED1 – weakening and destabilization of the total landscape/seascape functioning because of loss of ecosystem/habitat diversity
ED2 – influence of landscape heterogeneity on local species persistence
ED3 – influence of landscape heterogeneity on genetic diversity and evolution

per year of fish and invertebrates from 2009-2014, which represented approximately 17% of the animal protein consumed by humans (FAO, 2016). Oceans supports rapid socioeconomic development and growth of human population on coastlines, with increasingly intensive, multiple uses leading to heavily degraded habitats (Spalding *et al.*, 2014; Wong *et al.*, 2014). ***Marine populations and communities have been impacted at unprecedented rates*** by climate change (mainly in the form of ocean warming, ocean acidification, deoxygenation, and sea level rise) and direct anthropogenic activities (mainly in the form of fishing, pollution, and habitat degradation) (Chapter 2; Hoegh-Guldberg *et al.*, 2014; Poloczanska *et al.*, 2016; Pörtner *et al.*, 2014).

Globally, none of these pressures are projected to decrease in the future. Earth System Models have been used to project future environmental conditions (IPCC, 2013), showing that the state of the future ocean will strongly depend on the amount of carbon emitted in the coming decades (Gattuso *et al.*, 2015; IPCC, 2018). Climate change is, among other drivers, the main driver considered in global scale scenarios **(Table 4.2.2)**.

Mean sea surface temperature is projected to increase by +2.7°C in 2090-2099 as compared to 1990-1999 for the high emission scenario (RCP8.5), whereas the warming is limited to +0.71°C for the more stringent RCP2.6 emission scenario (Bopp *et al.*, 2013); model-mean values from the Coupled Model Intercomparison Project 5). At the regional scale, stronger warming occurs in the tropics, in the North Pacific and in the Arctic Ocean, with the sea surface warming more than +4°C at the end of the 21st century under RCP8.5 (Bopp *et al.*, 2013; Collins *et al.*, 2013).

As global temperatures rise, so does the **mean sea level** due primarily to the thermal expansion of ocean water and by melting of glaciers, ice caps and ice sheets. A sea level model calibrated with empirical data and forced by the IPCC high emission scenario (RCP8.5) projects a sea level rise (SLR) of 52-131 cm by 2100 relative to year 2000 (Kopp *et al.*, 2016).

A broadly uniform decrease of the **mean sea surface pH** of -0.33 pH units (model-mean) by the 2090s relative to the 1990s is predicted under RCP8.5 (Bopp *et al.*, 2013), which is accompanied by a decrease in carbonate ion concentration and in the saturation states of calcium carbonates (e.g., calcite, aragonite), essential components of shells or skeletons of many marine organisms. The volume of undersaturated waters with respect to aragonite is projected to increase between 1990 and 2100 from 76% to 91% of the global ocean under RCP8.5 (Gattuso *et al.*, 2015).

Earth system models also project **decreasing global ocean oxygen** due to climate change. The mechanisms at play are a reduction of oxygen solubility due to ocean warming and the combination of increased stratification and reduced ventilation that prevents the penetration of oxygen into the deep ocean (Breitburg *et al.*, 2018). Deoxygenation will continue over the 21st century irrespective of the future scenario, with decreases of global O_2 of -1.8% and -3.45% (model-mean) under RCP2.6 and RCP8.5, respectively (Ciais *et al.*, 2013), with a stronger drop for the North Pacific, the North Atlantic, and the Southern Ocean (Bopp *et al.*, 2013). Despite a consistent global deoxygenation trend across models, there is as yet no consensus on the evolution of hypoxic and suboxic

Table 4 2 2 **Major climate-related and direct human-mediated drivers of change impacting marine ecosystems (by IPBES subunits) as highlight in this chapter's sections 4.2.2.2 to 4.2.2.5.**

Cells are colored when there is substantial evidence from the reviewed scenarios and models that drivers have a major impact on one of the marine ecosystems. Where the information exists, the second column of the table reports the percentage of marine global scale scenarios implementing changes in the drivers and quantifying impacts on nature, based on our literature database (Appendix A4.1.1).

Direct drivers of change	Global scale	Open ocean pelagic	Polar seas	Shelf ecosystems					Deep sea ecosystems
				Tropical coral reefs	Rocky and sandy shores	Mangrove forests	Seagrass meadows	Kelp forests	
Climate-related drivers of change									
Ocean warming	45%	■	■	■	■	■	■	■	■
Ocean acidification	8%	■	■	■					■
Deoxygenation	4%	■		■			■		■
Sea ice melt	2%		■						
Sea level rise (SLR)	16%		■		■	■	■		
Extreme events	3%			■	■	■	■	■	
Direct human-mediated drivers of change									
Fishing	16%	■	■	■	■	■	■	■	■
Pollution	5%	■	■	■	■	■	■	■	■
Maritime transport		■	■						
Species introduction			■	■	■	■	■	■	
Land-use change	1%			■	■	■	■	■	
Coastal development	1%		■	■	■	■	■	■	
Aquaculture				■	■	■	■	■	
Oil and gas extraction, mineral mining		■	■	■	■				■
Main direct impacts on nature									
Habitat degradation			■	■	■	■	■	■	■
Biodiversity decline		■	■	■	■	■	■	■	■
Species invasion / range shift		■	■	■	■	■	■	■	
Shifts in food webs and biogeochemical cycles		■	■	■	■	■	■	■	■
Eutrophication				■	■		■		
Hypoxia		■		■	■		■		■

waters due to uncertainties in potential biogeochemical effects and in the evolution of tropical ocean dynamics (Cabré *et al.*, 2015). Along coastlines, deoxygenation and the increase of hypoxic "dead zones" are largely driven by direct human activities (which combine with sea warming), with rivers draining large nitrogen and phosphorus loads from fertilized agricultural watersheds, and from sewage, aquaculture and atmospheric nitrogen deposition, causing eutrophication and subsequent aerobic microbial decomposition (Glibert *et al.*, 2018; Levin *et al.*, 2009; Rabalais *et al.*, 2009).

Future climate change will hence alter marine habitats and modify biogeochemical cycles. Recent modelling work has shown that climate change may continue to produce more hostile conditions and threaten vulnerable ecosystems and species with low adaptive capacity (Gattuso *et al.*, 2015; Hoegh-Guldberg *et al.*, 2014; Mora *et al.*, 2013a; Pörtner *et al.*, 2014; Wong *et al.*, 2014).

Adding to future climate change and potentially amplifying impacts on marine ecosystems, direct human-mediated pressures will likely intensify in future. An **increase in fisheries and aquaculture production** is plausible as a response to increasing demand for fish and seafood (Chapter 11 of the World Ocean Assessment, UN, 2017) which is expected to arise as a result of population growth and increasing average income that allows for augmenting the proportion of fish in the diet (World Bank, 2013). Under assumptions of increasing technological efficiencies and increasing demand for fish, the FAO and OECD project that total world marine seafood production (fishery plus aquaculture) would exceed 120 million tons in 2025, or plus 17% relative to 2013-2015. Diverse forms of **pollution** (excessive nutrient loads, toxic contaminants, persistent organic pollutants, plastics, solid waste) will likely continue to pervade marine ecosystems in the future, constituting additional threats to living organisms (Bergman *et al.*, 2012; Geyer *et al.*, 2017; Lamb *et al.*, 2018; Sutton *et al.*, 2013; Worm *et al.*, 2017). The oceans are sinks for landborne and airborne inputs of persistent pollutants which can both travel great distances in the near-surface water masses (Eriksen *et al.*, 2014) of the open ocean, and sink into the deeper ocean (Chapter 20 of the World Ocean Assessment, UN, 2017). In coastal oceanic waters, increasing nutrient loads and pollution in combination with warming will likely stimulate eutrophication and increase the extent of oxygen minimum zones (Breitburg *et al.*, 2018; Rabalais *et al.*, 2009).

The impacts of global change on marine biodiversity will vary geographically, with latitudinal gradients of expected in many global scale scenarios (Gattuso *et al.*, 2015), and depending on the type of ecosystems **(Table 4.2.2)**. Major drivers of change in the open ocean pelagic ecosystems that are included in global scale models and scenarios are climate-related drivers (sea warming, acidification, deoxygenation), and fisheries exploitation. Additional future threats included in scenarios for shelf ecosystems are sea level rise, extreme events, nutrient pollution and coastal development which may cause degradation, fragmentation and loss of habitats **(Table 4.2.2)**.

Future scenarios of climate change impacts on marine biodiversity at global scales are the most documented in the literature (78% of the scenarios in our literature database – **Table 4.2.2**). They will therefore form the main content of this section (section 4.2.2.2), with evidence provided by type of ecosystems (IPBES units of analysis). The rest of the drivers are much less, or not at all, represented in scenarios projecting impacts on marine biodiversity at global scale, even though their historical and current impacts on biodiversity have been shown to be significant. Moreover, there are relatively few global scale scenarios involving multiple pressures on marine ecosystems and biodiversity (23% of the marine scenarios involve a combination of multiple drivers in our global scale literature database), so in addition to updating recent global assessments with the latest modelling and scenarios work, sections 4.2.2.2 to 4.2.2.5 report evidence from more local studies of how direct anthropogenic drivers may combine with climate change in impacting future marine biodiversity.

4.2.2.2 Future climate change impacts on marine biodiversity and ecosystem functioning

4.2.2.2.1 Climate change impacts in open ocean ecosystems

Low trophic levels

Net Primary Production (NPP) by marine phytoplankton is responsible for 50% of global carbon fixation through photosynthesis, but is also the basis of marine food webs, controlling the energy and food available to upper trophic levels. Earth System Models project a mean decrease of NPP in 2100 under all RCP greenhouse gas emissions scenarios, ranging from -3.5% to -9% under RCP2.6 (low emissions) and RCP8.5 (very high emissions), respectively (Bopp *et al.*, 2013), though there is significant variation between individual model projections. The global decrease of NPP is accompanied by a change in the seasonal timing of peak NPP, with an advance by ~0.5–1 months by 2100 globally, particularly pronounced in the Arctic (Henson *et al.*, 2013).

The projections are heterogeneous over space with general agreement that NPP is expected to decrease in the tropics and in the North Atlantic, and increase at high latitudes (Bopp *et al.*, 2013; Boyd *et al.*, 2014; Steinacher *et al.*, 2010). Some regional discrepancies between models exist, with nonlinear dynamics making some projections uncertain. In the tropics, the mechanisms at play are largely model-dependent, with both stratification–driven reduction in nutrient availability and increases in grazing and other phytoplankton loss processes (Laufkötter *et al.*, 2015). This results in large inter-model differences, with the decline in tropical NPP being projected between -1 and -30% by 2100 under RCP8.5 (Kwiatkowski *et al.*, 2017). Using satellite-based observations of ocean–colour and an emergent-constraint relationship, the uncertainties in the decline of tropical NPP have been reduced with an estimated decline of -11±6% in 2100 for a business-as-usual scenario (Kwiatkowski *et al.*, 2017).

In the Arctic, some models project an increase in NPP because of the loss of perennial sea-ice and an increase of light availability, whereas other models simulate a decrease due to increasing ocean stratification and decreasing nitrate availability (Vancoppenolle *et al.*, 2013). In the Southern Ocean, models project a zonally-varying response of NPP to climate change, with a decrease in the subpolar band (50°S and 65°S), but increases in the Antarctic (south of 65°S) and in the transitional band (40°S-50°S) (Leung *et al.*, 2015). Mechanisms at play are changing light availability and iron supply by sea ice melting (Wang *et al.*, 2014).

Under the SRES A1B scenario, the reduction in zooplankton biomass was projected to be higher than for primary production in 47% of the ocean surface particularly in the tropical oceans, implying negative amplification of ocean warming through bottom-up control of the food web (Chust *et al.*, 2014). This impact differs regionally with positive amplification of zooplankton biomass in response to the increase of NPP in the Arctic and Antarctic oceans, thereby increasing the efficiency of the biological pump in those regions. Other changes in species composition can be expected under future climate change, such as shifts from diatom-dominated phytoplankton assemblages with high POC export efficiencies to smaller, picoplankton communities characterized by low export efficiencies (Morán *et al.*, 2015; Smith *et al.*, 2008).

In addition to warming and changes in ocean stratification/circulation, ocean acidification is also expected to influence metabolic processes in phytoplankton and zooplankton species. Laboratory and mesocosm experiments have shown contrasting responses for different plankton types under elevated CO_2 concentrations, with a stimulating influence for nitrogen-fixing cyanobacteria (Hutchins *et al.*, 2007, 2013) and pico-eukaryotes (Bach *et al.*, 2017), but potential detrimental effects on growth and calcification rates for some of the main calcifying phytoplankton (Meyer & Riebesell, 2015). Other potential effects of ocean acidification include a reduction in microbial conversion of ammonium into nitrate (Beman *et al.*, 2011), which could have major consequences for oceanic primary production and potentially less carbon export to the deep sea. A recent modeling study incorporating differing growth responses of phytoplankton types to increased pCO_2, has suggested that acidification effects may even outrank the effects of warming and of reduced nutrient supply on phytoplankton communities over the 21st century (Dutkiewicz *et al.*, 2015).

Higher trophic levels

Most published global scale scenarios of change in higher trophic levels in response to climate change rely on correlative models examining changes in species' spatial distribution (64% of publications on the effect of climate change on marine biodiversity at global scale in our literature database*,* Appendix A4.1.1). These "Species Distribution Models" (SDMs) (also called ecological niche models or climate envelope models) analyze the statistical relationship between species occurrences and a set of environmental variables (Araújo & New, 2007; Thuiller *et al.*, 2009). SDMs do not typically consider species adaptation nor the effects of species interactions.

Using species distribution models for projecting future climate-induced changes, the main findings at the global scale are that species will shift their distribution poleward (Cheung *et al.*, 2009), likely resulting in an increase in species richness and species invasions in high latitude regions (the Arctic and Southern Ocean) and conversely a decrease of species richness in the tropics and the equator (García Molinos *et al.*, 2016; Jones & Cheung, 2015; Pörtner *et al.*, 2014) and in semi-enclosed seas (e.g., Mediterranean Sea, Ben Rais Lasram *et al.*, 2010). A mean latitudinal range shift of 25.6 km per decade to 2050 was projected under the high emission scenario RCP8.5, which reduced to 15.5 km per decade under RCP2.6 (Jones & Cheung, 2015).

Distributional shifts of marine species are the most clearly detectable pattern that can currently be assigned to climate change, or more specifically to sea surface temperature change (García Molinos *et al.*, 2016). This is related to the sensitivity of marine ectotherms, which constitute the bulk of high trophic level species, to temperature change. But ocean warming can trigger additional adaptive responses such as phenological shifts and physiological changes in growth and reproduction. It is expected that animals inhabiting temperate latitudes, where seasonality is strong, will better adapt to a changing climate whereas polar stenotherm species will be more vulnerable to warming (Pörtner *et al.*, 2014). Tropical species, in addition to having narrow thermal windows, inhabit the warmest waters and are thus near physiological temperature tolerance limits that lower their adaptive capacity (Storch *et al.*, 2014)
At low latitudes, open-ocean oxygen-minimum zones (OMZ) constitute an additional threat to marine organisms, especially in the eastern tropical Pacific (Cabré *et al.*, 2015)

and along major eastern boundary upwelling systems (Gilly *et al.*, 2013). The horizontal and vertical expansion of already large OMZs will potentially affect marine populations dramatically, through shifts in their spatial distribution and abundance, as well as altered microbial processes and predator-prey interactions (Breitburg *et al.*, 2018; Gilly *et al.*, 2013). The shoaling of the upper boundary of the OMZs can also trap fish in shallower waters, compressing their habitat, and thereby increasing their vulnerability to predation and fishing (Bertrand *et al.*, 2011; Breitburg *et al.*, 2018).

In addition to correlative species distribution models, there are recently developed integrated modelling approaches (e.g., end-to-end models combining the physics of the ocean to organisms ranging from primary producers to top predators) considering the multiple responses of marine populations to climate change (based on e.g., physiological rates, trophic interactions, migration behavior), as well as essential food web knock-on effects and adaptive mechanisms to move towards more realistic projections of marine biodiversity (Payne *et al.*, 2016; Rose *et al.*, 2010; Stock *et al.*, 2011; Tittensor *et al.*, 2018a; Travers *et al.*, 2007). At regional and local scales, such models have been developed with more detailed representation of multiple taxa of commercial interest or of conservation concern than at the global scale, where the few existing end-to-end models represent ecosystems and biodiversity through large functional groups (e.g. fish biomass, pelagic biomass, biomass in different size classes) or are focused on single key species. A global scale end-to-end model run under the worst-case scenario (RCP8.5) projected that the biomass of high trophic level organisms would decrease by 25% by the end of the century (Lefort *et al.*, 2015). This first estimate, which has been recently confirmed by an ensemble of global marine ecosystem models **(Box 4.2.2)**, suggests that the response of high trophic levels amplifies the decrease of biomass projected for phytoplankton and zooplankton.

Global scale models project that ocean warming may shrink the mean size of fish by the end of century (Cheung *et al.*, 2013; Lefort *et al.*, 2015) and lead to smaller-sized infaunal benthos globally (Jones *et al.*, 2014). This trend is very robust to the model used in the different studies, as well as to the mechanisms involved: the decrease in mean size could be either due to the combined effects of future warming and deoxygenation on animal growth rates (Cheung *et al.*, 2013), the combined effects of warming and food limitation (Lefort *et al.*, 2015), or to the limiting flux of particulate organic matter from the upper ocean to the benthos (Jones *et al.*, 2014).

Air-breathing marine species

Marine turtles are particularly vulnerable to climate change as, being ectotherms, their behavior, physiology, and life traits are strongly influenced by environmental factors (Janzen, 1994; Standora & Spotila, 1985). Arguably, the most detectable impacts will occur during the terrestrial reproductive phase: incubating eggs are vulnerable to sea-level and extreme weather events (Fish *et al.*, 2005; Fuentes *et al.*, 2010), while future changes in temperature and rainfall at nesting beaches will likely reduce hatching success and emergence, cause a feminization of turtle populations, and produce hatchlings with higher rates of abnormalities (Fisher *et al.*, 2014; Mrosovsky & Yntema, 1980). Future changes in temperature are expected to impact the frequency and timing of nesting (Fuentes & Saba, 2016; Limpus & Nicholls, 1988; Saba *et al.*, 2007), as well as marine turtle distribution (McMahon & Hays, 2006; Pikesley *et al.*, 2015; Witt *et al.*, 2010). Foraging specialists (i.e. leatherbacks) might be more susceptible to climate change impacts on the marine food web relative to foraging generalists (i.e. loggerheads) due to a lesser ability to switch prey type (Fuentes & Saba, 2016). Ultimately, impacts will depend on populations' resilience and ability to adapt. Some marine turtle populations are already responding to climate change by redistributing their nesting grounds and shifting their nesting phenology (Pikesley *et al.*, 2015). However, it is still unclear whether marine turtles will be able to fully adapt since climatic changes are occurring more rapidly than in the past and are accompanied by a variety of anthropogenic threats (e.g., fisheries by-catch, pollution) that make them more vulnerable and decrease their resilience (Fuentes *et al.*, 2013; Poloczanska *et al.*, 2009).

Seabirds responses to future climate change are commonly predicted using species distribution models. Shifts and contractions in foraging habitat could be particularly problematic for seabirds by increasing energetic expenditures. For example, the summer foraging areas for king penguins are predicted to shift southward in response to an intermediate warming scenario (SRES A1B), doubling the travel distance to optimal foraging areas for breeders with likely negative consequences for population performance (Peron *et al.*, 2012). Poleward shifts in foraging areas are also projected for seven Southern Ocean albatross and petrel species under a range of emission scenarios, with associated range contractions of up to 70% for wandering and grey-headed albatross by 2050 (Krüger *et al.*, 2018). For other species (e.g., the endangered Barau's storm petrel), climate-driven shifts and contractions in wintering range are predicted but the overall population consequences are unclear (Legrand *et al.*, 2016). Fewer studies have coupled mechanistic population models with climate projections to estimate future population trajectories. Cassin's auklets are predicted to decline by 11-45% by 2100 under a mid-level emission scenario, due to increased sea surface temperatures and changes in upwelling dynamics within their foraging range (Wolf *et al.*, 2010). Contrasting responses to future climate scenarios were reported in three seabirds (albatrosses and petrel),

Box 4 2 2 Ensemble model projections of marine ecosystem futures under climate change.

Model intercomparison studies use a common set of input conditions to force a suite of potentially very different models to then produce an 'ensemble' of outputs. These outputs can be compared to examine differences among models, and provide a multi-model mean and range of uncertainty for end users. While such studies are a common tool in the Earth system and climate modelling communities, their application to biodiversity and ecosystems, particularly in the marine realm, remains relatively new.

Fish-MIP (Tittensor *et al.*, 2018b) is the first model intercomparison project examining the impacts of climate change on fisheries and marine ecosystems at regional to global scales using a common set of climate change scenarios. There have been many different attempts to model the ocean ecosystem resulting in a large diversity of models with various purposes – from examining species distributions to ecosystem structure to fisheries catch potential (Tittensor *et al.*, 2018b). Fish-MIP provides a common simulation framework and standardized forcing variables to provide consistent inputs to these models and prescribes a common set of consistent outputs for analysis. In the first round of Fish-MIP, the focus was on examining climate change (rather than fisheries) both regional and global scales. Here, marine animal biomass includes mostly fish, but in some models, invertebrates and marine mammals are also considered.

The results across six global marine ecosystem models (APECOSM, BOATS, DBEM, DPBM, EcoOcean, Macroecological) that were forced with two different Earth-system models (ESMs) and two emission scenarios (RCPs 2.6 and 8.5) show that ocean animal biomass will likely to decline over the coming century under all climate change scenarios (Figure 4.2.4; Lotze *et al.*, 2018; Tittensor *et al.*, 2018b). The ensemble model means show steeper declines under RCP8.5 (highest emission scenario) than RCP2.6 (high mitigation scenario), and steeper declines when forced with the ESM IPSL-CM5A-LR than GFDL-ESM2M. The trajectories from different ESMs and RCPs remain relatively similar until about 2030 to 2050, after which they begin to diverge markedly. Thus, by 2100, the model-mean animal biomass is projected to decline between 3% and 23% **(Figure 4.2.4)**. These declines are largely driven by a combination of increasing water temperature and declining primary productivity, and are likely to impact ecosystem services including fisheries (Blanchard *et al.*, 2017).

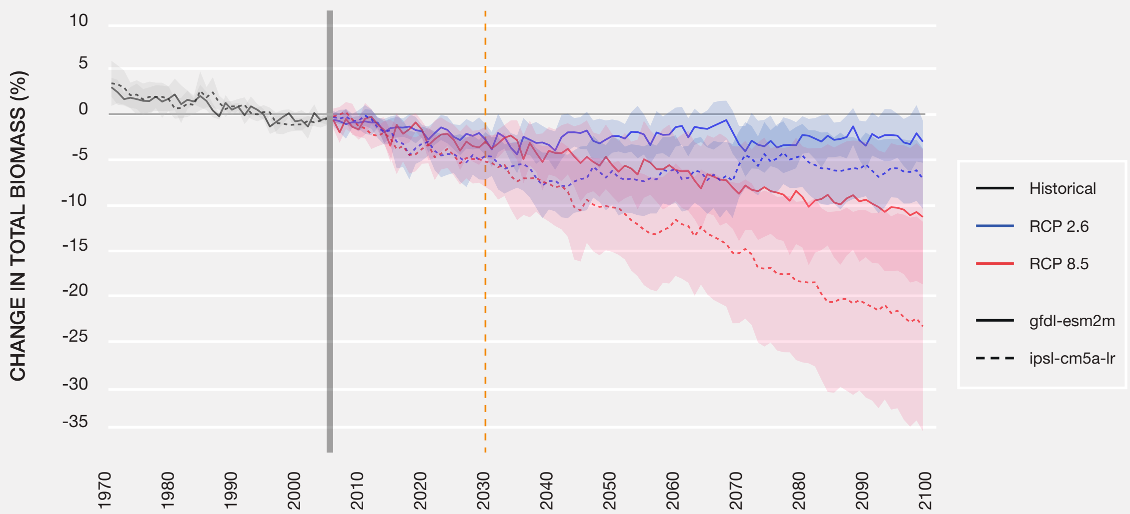


Figure 4 2 4 Ensemble projections of global ocean animal biomass under different scenarios of climate change.

Projections represent the multi-model means of six global marine ecosystem models forced by marine environment change projected by two different Earth-system models: GFDL-ESM2M (solid lines) and IPSL-CM5A-LR (dashed lines) and two greenhouse gas emission scenarios: RCP2.6 (low emissions; blue) and RCP8.5 (very high emission; red) with no fishing signal imposed (i.e., changes are due only to climate). Shaded areas represent one inter-model standard deviation (ecosystem models). All percentage changes are relative to a 1990-1999 baseline. The vertical grey line separates historical and future projections for climate forcing; the vertical dashed orange line represents the 2030 target year for the Sustainable Development Goals. Data source: Tittensor *et al.* (2018b); Lotze *et al.* (2018).

Spatial maps of ensemble projections (**Figure 4.2.5**; Lotze *et al.*, 2018; Tittensor *et al.*, 2018b) show broad-scale decreases in animal biomass in tropical and many temperate regions, and potential increases in polar regions. While ensemble projections across many models are more likely to capture plausible trends than any single model, there was more variation among models in polar and some coastal regions, suggesting that there is greater uncertainty about projected outcomes.

The results shown here for global marine ecosystem models are helpful for describing the global trends but may not capture the complex dynamics at local and regional scales. Forthcoming analyses should therefore compare regional projections based on regional scale models and global models and examine the variability between regional models to provide projections and measures of uncertainty at scales better matched to the needs of resource managers. Moreover, different scenarios of fishing pressure need to be incorporated to examine interactions between fishing and climate change impacts.

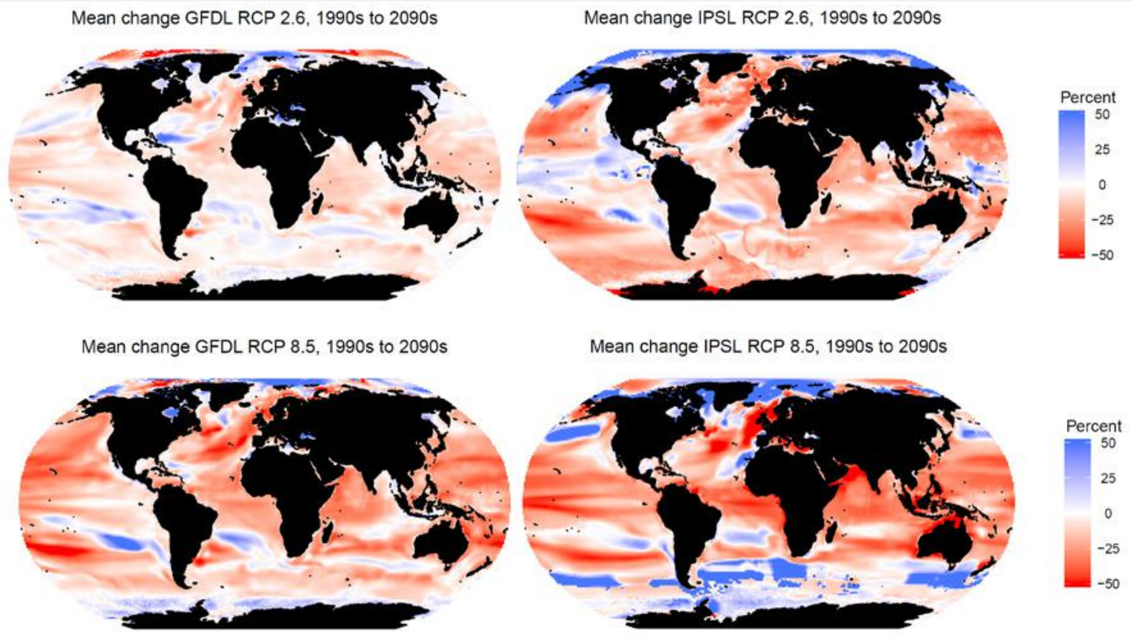


Figure 4 2 5 **Global ensemble mean spatial patterns of change in global ocean animal biomass under RCP2.6 (low greenhouse gas emissions; top) and RCP8.5 (very high emissions; bottom) forced by GFDL-ESM2M (left) and IPSL-CM5A-LR (right) Earth System Models.**

Percentage changes are relative to a 1990-1999 baseline. Data source: Tittensor *et al.* (2018b); Lotze *et al.* (2018).

owing to differences in life histories and distribution area (Barbraud *et al.*, 2011). These studies have identified strong non-linearities in demographic responses, suggesting the potential for threshold effects under future climate extremes (Pardo *et al.*, 2017).

Marine mammals, as homeotherms, are physiologically buffered from some direct effects of temperature rise. Rising ocean levels from ocean warming and ice melt will likely lead to a loss of land or ice-based habitat available for breeding or pupping, particularly for marine mammals on low-lying atolls or ice-dependent breeders (Baker *et al.*, 2006; Laidre *et al.*, 2015). A global assessment of climate change effects on marine mammals used a range of climate scenarios (warming between 1.1°C and 6.4°C) to qualitatively rank negative population effects for all marine mammal species (MacLeod, 2009). It showed that species tied to land, ice, or facing geomorphic barriers were most likely to be affected.

4.2.2.2.2 Climate change impacts in shelf ecosystems

Tropical Coral Reefs

An unprecedented 3-year (2014-2017) marine heat wave have damaged most of coral reefs on Earth (75%) with still unassessed social-ecological consequences (Eakin *et al.*, 2018). Thermal stress disrupts the relationship between corals and their algal symbionts, with bleached corals being physiologically damaged and suffering severe mortality rate. The number of years between recurrent severe coral-bleaching events has diminished fivefold in the past four decades, from once every 25 to 30 years in the early 1980s to once every 5.9 years in 2016 (Hughes *et al.*, 2018). A full recovery of mature coral assemblages, source of reef biodiversity and productivity, generally takes from 10 to 15 years for the fastest growing species (Hughes *et al.*, 2018). Many reefs, including those of the iconic and well-protected Great Barrier Reef, have experienced a shift from dominance of branching tabular species that build 3-dimensional habitats, towards corals with simpler morphological characteristics (Hughes *et al.*, 2018). A trophic model showed that a loss of coral complexity could cause more than a 3-fold reduction in fishery productivity (Rogers *et al.*, 2014), due to the preferential settling of juvenile fishes in unbleached coral habitat (Scott & Dixson, 2016).

In addition to thermal stress, ocean acidification represents a major threat to marine calcifier organisms like corals, particularly those building large but low-density skeletons. A decrease of pH by 0.4 units (expected under RCP8.5; Hoegh-Guldberg *et al.*, 2014) would translate into a coral habitat complexity loss of 50%, inducing a decrease in species richness by 30% for both fish and invertebrates (Sunday *et al.*, 2017). A seawater pH lowered by just 0.14 units (RCP2.6) would induce a loss of 34% net community calcification (Albright *et al.*, 2018). Projections anticipate a shift from a state of net accretion to net dissolution before the end of the century (Eyre *et al.*, 2018). Anoxic events are also rapidly increasing in prevalence worldwide and cause underestimated mass mortality on coral reefs (Altieri *et al.*, 2017).

To better anticipate and simulate the potential futures of coral reef habitats, two complementary approaches have been used. First, laboratory and field experiments try to estimate the tolerance, acclimatization and adaptability of coral species and their symbionts to environmental changes. One of the most striking studies demonstrates that progressive acclimatization, even to temperatures up to 35°C, can achieve the same heat tolerance as expected from strong natural selection over many generations (Palumbi *et al.*, 2014). This suggests that at temperatures beyond the thermal limits of coral species, the rate and speed of temperature change is key to explain coral bleaching. Experiments also allow testing of the interactions of multiple stressors. For instance, a 3-year field experiment deciphered the mechanisms by which elevated temperatures exacerbate overfishing and nutrient pollution effects on corals by increasing coral–algal competition and reducing coral recruitment, growth and survivorship (Zaneveld *et al.*, 2016).

Second, models attempt to simulate the futures of tropical coral reefs under various scenarios. A simulation based on genomic models predicting future evolution and persistence in a high-latitude population of corals from Cook Islands (South Pacific) showed a rapid evolution of heat tolerance resulting in population persistence under mild warming scenarios (RCP2.6 and RCP4.5) though this adaptation would not be rapid enough to prevent extinction under more severe scenarios (RCP6.0 and RCP8.5; Bay *et al.*, 2017). Other studies based on niche models, that can also integrate adaptation capacity related coral cover to environmental variables allowing for projections at global (Logan *et al.*, 2014) and regional (Ainsworth *et al.*, 2016) scales. For instance, coral cover on the Great Barrier Reef was projected to remain lower than 5% before the end of the century under a high emission scenario (RCP8.5) (Ainsworth *et al.*, 2016).

Rocky and sandy shores

Straddling the intersection between land and ocean, rocky and sandy shores are the dominant components of coastlines globally, are the most accessible of the marine biomes and supply services in terms of coastal protection, direct provisioning (food and materials), recreation (tourism, fishing), spiritual and cultural purposes, and substrate for aquaculture and infrastructure.

These ecosystems are vulnerable to sea-level rise which adds to the height of sea-level extremes, such as during storm surges, and can exacerbate projected changes in wave impacts (Hemer *et al.*, 2013). Sea level rise can affect the dynamics of the morphology of beach systems, as well as increasing coastal inundation risk, leading to erosion in many cases, as well as increasing threats to nesting beaches for turtles and seabirds, dune vegetation and coastal infrastructure and assets (e.g., de Winter & Ruessink, 2017; Jevrejeva *et al.*, 2016; Pike *et al.*, 2015).

Evidence of species responses to warming oceans are recorded from sandy and rocky shores globally, showing that barnacles, mollusks, crabs and macroalgae have shifted their distributions in response to recent warming (e.g., Johnson *et al.*, 2013; Pitt *et al.*, 2010; Poloczanska *et al.*, 2013; Schoeman *et al.*, 2015; Wethey *et al.*, 2011). For example, the cold-water barnacle *Semibalanus balanoides* may disappear from south-western English shores by 2050 (Poloczanska *et al.*, 2008). The frequency of temperature extremes is projected to increase in the next few decades, particularly during summer in regions such as the Mediterranean (Kirtman *et al.*, 2013), with potential high ecosystem impact as large-scale mortalities of intertidal species have been recorded during extreme heat events (Garrabou *et al.*, 2009; Wernberg *et al.*, 2013). In south-east Australia, the temperature-driven range extension of the sea urchin *Centrostephanus rodgersii* has led to the loss and overgrazing of kelp beds and a reduction in associated biodiversity (Johnson *et al.*, 2011; Ling *et al.*, 2015).

Forests of kelp, large brown temperate-coast marine algae, are themselves directly impacted by climate change. Under RCP2.6 and RCP8.5 scenarios, models of kelps in the

North Atlantic incorporating changes in temperature, salinity, and sea ice cover predict northern movement and range contraction by 2090 (Assis *et al.*, 2017a, 2017b, 2016; Raybaud *et al.*, 2013). Under RCP8.5, areas such as the Gulf of Maine, Southern Europe, and the northwestern coast of Africa would be bereft of kelps (Assis *et al.*, 2017a), a trend which in some of these systems is already observed now (Filbee-Dexter *et al.*, 2016; Krumhansl *et al.*, 2016). The Arctic, conversely, is projected to gain kelps, which is consistent with observations of kelp increases in areas that are decreasing in sea-ice cover and hence increasing in light availability (Bartsch *et al.*, 2016). The area gained is not projected to counterbalance the area lost. Similarly, in Japan, models project its southernmost species, *Ecklonia cava*, to colonize new northern habitats that are currently occupied by colder water kelps, due to a combination of shifting temperatures and increases in grazing by warm water fishes under all RCP scenarios by 2090. Further scenario-based modeling efforts are needed for Australia, New Zealand, the Southern Atlantic, and the Pacific Coasts of the Americas, where models of climate change's future impacts on kelps have been less explored. While modeled predictions typically report declines or polar movement, the observed long-term trajectories of kelp forests are currently mixed (Krumhansl *et al.*, 2016). In some cases, such as South Africa, this is due to local cooling (Blamey *et al.*, 2015; Bolton *et al.*, 2012). In others, climate driven range expansions of urchin predators has also driven local increases (Fagerli *et al.*, 2014), although the longevity of this trend is unclear as they can be overridden by physical drivers (Moy & Christie, 2012).

Coastal wetlands

Coastal wetlands are found along coastlines globally, and include salt marshes (mostly found along temperate, boreal and arctic coastlines), mangroves (mostly found in tropical and subtropical areas), tidal flats, and seagrasses. They form essential marine vegetated habitats for carbon sequestration, and coastal protection against increased sea level rise (SLR) and natural hazards (Alongi, 2008; Duarte *et al.*, 2013; Fourqurean *et al.*, 2012). They also host a great diversity of species, playing a major role as nursery and breeding areas for a wide variety of marine fauna organisms (Heck Hay *et al.*, 2003), including migratory ones such as coastal birds (Nuse *et al.*, 2015) or coral reef fish species (Harborne *et al.*, 2016). Climate changes in the form of warming, sea level rise and increased extreme events (e.g. hurricanes) may increase the vulnerability of these ecosystems in the future. Vegetated coastal habitats are already declining globally (Duarte *et al.*, 2005), and many species are threatened with extinction (Polidoro *et al.*, 2010; Short *et al.*, 2011). The recent IPCC report on « Global warming of 1.5°C » (IPCC, 2018) assessed that at global warming limited to 1.8°C above the pre-industrial level, the risks to mangroves will remain medium (e.g., not keeping pace with SLR; more frequent heat stress mortality) whereas seagrasses are projected to reach moderate to high levels of risk (e.g., mass mortality from extreme temperatures, storm damage) (Hoegh-Guldberg *et al.*, 2018).

Sea level rise can have large impacts on coastal ecosystems because of the flat, gentle slope of much coastal land. Although coastal wetlands are dynamic ecosystems that can adapt to sea level rise, their capacity to do so is limited, regionally differentiated and is affected by many human activities (Kirwan & Megonigal, 2013; Schuerch *et al.*, 2018; see 4.2.2.5). The response of wetlands to sea level rise involves landward migration of vegetated areas, and submergence at lower elevations (Wong *et al.*, 2014). Acceleration of sea level rise threatens future wetlands capacity to adapt with occurrence of horizontal retreat, and vertical drowning, when accretion of sediment and organic matter cannot keep pace with SLR (Spencer *et al.*, 2016). A meta-analysis estimated that under RCP2.6, 60% of the saltmarshes will be gaining elevation at a rate insufficient to keep pace with SLR by 2100, and the loss could reach 90% under high SLR (RCP8.5) (Crosby *et al.*, 2016). Such high SLR (1m by 2100) could put at risk 68% of coastal wetlands in developing countries (Blankespoor *et al.*, 2014). By contrast, a just published integrated model, taking into account the capacity of wetlands to both expand horizontally by inland migration and build up vertically by sediment accretion, projected less pessimistic impacts of SLR with the loss of global coastal wetlands area ranging between 0 and 30% by 2100, depending on the RCP considered (Schuerch *et al.*, 2018). Sea level rise and storm surges cause salinity intrusion inland, that can impact coastal and freshwater wetlands, with various effects such as decreased inorganic nitrogen removal, decreased carbon storage, and increased generation of toxic sulphides (Herbert *et al.*, 2015). Increased salt and sulphide concentrations induce physiological stress in biota and ultimately can result in large shifts in communities and associated ecosystem functions. Because impacts of sea level rise are so prominent in coastal wetlands (Jennerjahn *et al.*, 2017), the impacts of temperature rise have been relatively less explored despite their importance in terms of ecosystem structure and function (Gabler *et al.*, 2017).

Submerged plants such as seagrass are highly impacted by temperature extremes. Warming-induced deterioration of seagrass ecosystems has been observed over recent decades in the West Atlantic, Mediterranean, and Australia, with summer temperature spikes often leading to widespread seagrass mortality (Fraser *et al.*, 2014; Jordà *et al.*, 2012; Moore & Jarvis, 2008; Short & Neckles, 1999). In the western Mediterranean Sea, a model relating mortality rates to maximum sea temperature projected that seagrass meadows may become functionally extinct by 2050–2060, under the SRES A1B emission scenario (Jordà *et al.*, 2012). Climate warming is also affecting other components of seagrass ecosystems, notably via 'tropicalization'—increasing representation of tropical species—among seagrass-associated fish communities (Fodrie *et al.*, 2009), with the potential to reduce seagrass biomass and habitat complexity as tropical herbivorous fishes increase (Heck *et al.*, 2015). Among the most serious concerns is rising frequency of disease epidemics and prevalence of pathogens, which are associated with warming in many systems, and that could trigger widespread die-offs of seagrass (Altizer *et al.*, 2013; Harvell *et al.*, 2002; Kaldy, 2014; Sullivan *et al.*, 2013).

Under elevated mean global temperatures, mangroves are expected to displace salt marshes in many areas as the limits to mangrove growth imposed by cold events decrease (Short *et al.*, 2016). Mangroves in the southeastern US have been projected to expand in area (Osland *et al.*, 2013), consistent with observed trends across five continents over the past 50 years (Cavanaugh *et al.*, 2014; Saintilan *et al.*, 2014). These projections overlook important differences among mangrove species, and also depend on mangroves' ability to successfully migrate landward (Di Nitto *et al.*, 2014), and to build up sediment or continue to receive allochtonous sediment inputs from estuarine or freshwater sources at rates apace with SLR (Lovelock *et al.*, 2015; Parkinson *et al.*, 1994). In coastal settings experiencing erosion, an expansion of mangroves is highly unlikely. On the other hand, expansion is seen in areas of accelerating sediment deposition due to upstream land-use changes (Godoy & de Lacerda, 2015). Species distribution modeling studies have projected geographically dependent shifts in community composition and species richness under climate change scenarios (Record *et al.*, 2013). While species richness is projected to increase in SE Asia, South America, eastern Australia and parts of the African coasts, it will likely decline in Central America and the Caribbean, partly linked to increased intensity and frequency of tropical storms, as well as in northern Australia (Record *et al.*, 2013).

Under increased CO_2, the productivity of wetlands vegetation (seagrass, mangrove trees, saltmarsh plants) is expected to increase in the future (Wong *et al.*, 2014). Seagrasses are likely to be among the species that perform better in a more acidified ocean, because their growth can benefit from increasing dissolved CO_2 (Koch *et al.*, 2012). This simulation result is supported by greater growth rates reported around natural marine CO_2 seeps, where seagrass sequestered considerably more carbon below-ground under acidified conditions, suggesting a possible feedback to reduce the impacts of CO_2 injection into marine waters (Russell *et al.*, 2013). However, there is limited evidence that elevated CO_2 will increase seagrass resistance to warming (Jordà *et al.*, 2012). For mangroves, increased CO_2 has been linked to variable responses in net primary productivity, with decreased NPP projected for *Laguncularia racemosa* and increased NPP for *Rhizophora mangle* (Farnsworth *et al.*, 1996; Snedaker & Araújo, 1998). Such variation may be due in part to methodological differences, but may also reflect important variations in regional conditions (McKee, 2011).

4.2.2.2.3 Climate change impacts in deep seas

The deepsea (defined here as >200m depth) covers about 60% of global ocean area and represents the largest ecosystem in the world (Smith *et al.*, 2009; Watling *et al.*, 2013), accounting for more than 95% of the volume of the Earth's oceans. Deep sea ecological processes and characteristics (e.g., nutrient cycling, productivity) underlie the healthy functioning of ocean ecosystems and provide valuable services to mankind (Thurber *et al.*, 2014).

Many observational studies have shown that present-day climate change is already impacting deep sea environments due to increased temperature (Purkey & Johnson, 2010), deoxygenation (Helm *et al.*, 2011; Keeling *et al.*, 2010; Stramma *et al.*, 2008, 2012), lowered pH of intermediate deep-waters (Byrne *et al.*, 2010), and altered particulate organic carbon (POC) flux to the seafloor (Ruhl & Smith, 2004; Smith & Stephenson, 2013). Elevated seafloor temperatures (3.7°C at the bathyal seafloor by 2100 under RCP8.5; Mora *et al.*, 2013b; Sweetman *et al.*, 2017) will lead to warming boundary currents which has the potential to massively release methane from gas hydrates buried on margins (Johnson *et al.*, 2015; Phrampus & Hornbach, 2012), especially in the Arctic, with simultaneous effects on water column de-oxygenation and ocean acidification (Biastoch *et al.*, 2011; Boetius & Wenzhöfer, 2013). Along canyon-cut margins such as those that occur in the western Mediterranean, warming may additionally reduce density-driven processes, leading to decreased organic matter transport to the seafloor (Canals *et al.*, 2006).

Climate change is also likely to increase wind-driven upwelling in eastern boundary currents, stimulating photosynthetic production at the surface (Bakun, 1990; Bakun *et al.*, 2015; Wang *et al.*, 2014). This new production may, however, decay as it sinks and increase biogeochemical drawdown of O_2. Upwelling may also bring low-O_2, high-CO_2 water onto the shelf and upper slope (Bakun, 1990; Bakun *et al.*, 2010; Feely *et al.*, 2008; Sydeman *et al.*, 2014; Wang *et al.*, 2014). The expansion of hypoxic zones is expected to affect many aspects of deep-sea ecosystem structure and function (Gooday *et al.*, 2010).

As O2 levels decline, many species of deep water octocorals (including gorgonians and pennatulaceans) which provide habitat for a diverse array of invertebrates, are expected to decrease in abundance (Buhl-Mortensen *et al.*, 2010; Etnoyer & Morgan, 2005; Murray Roberts *et* *al.*, 2009). Acidification of deep waters has been projected to negatively impact cold-water stony corals (Scleractinia), particularly in the North Atlantic (Tittensor *et al.*, 2010). Single stressors like warming will also limit tolerance windows for other stressors such as low O2 or low pH (Pörtner, 2012; Pörtner & Knust, 2007).

With the projected global reduction in the biomass of phytoplankton in the upper ocean (Bopp *et al.*, 2013; section 4.2.2.2.1), the flux of particulate organic carbon (POC) to feed open ocean seafloor communities is expected to decrease, causing potential alterations of the biomass, composition and functioning of the benthic communities. Reductions in seafloor POC flux will be most drastic in the oceanic gyres and equatorial upwelling zones, with the northern and southern Pacific Ocean and southern Indian Ocean gyres projected to experience as much as a 32–40% decline in POC flux by the end of the century (CMIP5, RCP8.5; Mora *et al.*, 2013b; Sweetman *et al.*, 2017). Recent studies have suggested that the NE Atlantic Ocean could also undergo similar reductions in POC flux (Jones *et al.*, 2014). The abyssal ocean is highly sensitive to changes in the quantity and quality of POC flux that could affect the biomass of benthic microbial and faunal biomass, and cause dramatic reductions in the sediment mixed-layer depth, benthic respiration, and bioturbation intensity (Jones *et al.*, 2014; Smith *et al.*, 2008; Sweetman *et al.*, 2017). These changes have the potential to feed back on global carbon cycling and ultimately C-sequestration (Thurber *et al.*, 2014).

4.2.2.2.4 Climate change impacts in polar seas

Rising temperatures are projected to reduce sea ice extent and volume in the Arctic and Antarctic, some of the fastest warming places on Earth (IPCC, 2013). The rapid rate at which sea ice retreats in polar seas implies major changes to be expected in the future for biodiversity and ecosystem function (Gutt *et al.*, 2015; Larsen *et al.*, 2014; Wassmann *et al.*, 2011). All components of the food webs will potentially be impacted, from phytoplankton to top predators, and from pelagic to benthic species.

Multiple lines of evidence show that ice-melting is likely to increase primary productivity in polar seas due to increased light availability, although this could be dampened by a decrease in nutrient supply due to enhanced water column stratification that is expected from warming and freshening of surface waters (section 4.2.2.2.1; Hoegh-Guldberg *et al.*, 2018; Larsen *et al.*, 2014). It has also been shown that the increased production of floating icebergs, enriched with terrigenous material, might significantly elevate nutrient levels and primary production (Smith *et al.*, 2007). However, while primary production may increase in polar seas in the future, warmer waters can cause a shift in the composition of the zooplankton community, such as the shift from *Calanus glacialis* towards dominance of the smaller, less energy-rich *Calanus finmarchicus* in Arctic waters (Kjellerup *et al.*, 2012), with potential huge consequences up the food chain. By contrast, in coastal areas, the production and transport of organic matter to the seafloor may decline because glacial meltwater and erosion of melting tundra (Węsławski *et al.*, 2011) will likely enhance water column turbidity, which results in decreased water column light levels (Grange & Smith, 2013; Sahade *et al.*, 2015). The increased sedimentation in deep coastal areas, particularly in Arctic fjords, may also smother or clog the breathing and feeding apparatus of sessile suspension-feeders (e.g., corals and sponges), induce O_2 stress, but may favour ophiuroids and capitellid polychaetes (Sweetman *et al.*, 2017; Wlodarska-Kowalczuk *et al.*, 2005).

Changes in primary production and resulting POC flux to the seafloor will have impacts on ecosystem structure and function. Elevated POC flux increases the abundance and diversity of benthic communities, the prevalence of habitat-forming taxa (sponges, benthic cnidarians), and the extension of species ranges into deeper waters (De Rijk *et al.*, 2000). It could also trigger the switch from dominance by bacteria to dominance by metazoans for processing benthic organic matter with bottom-up consequences on the food-web (Sweetman *et al.*, 2014). Changing ice regimes may also result in physical disturbance of the deep sea, as large icebergs can scour the sediment down to 400m on the Antarctic shelf, enhancing seafloor heterogeneity and creating hard substrates for sessile megafauna (Meyer *et al.*, 2015, 2016; Schulz *et al.*, 2010). In the longer term, iceberg scouring and dropstone deposition will tend to elevate diversity on regional scales through (re)colonization processes, although the immediate effect of scouring will be local elimination of many species (Gutt & Piepenburg, 2003; Gutt *et al.*, 1996; Thatje *et al.*, 2005).

Sea ice melting is also expected to impact species up the food-web, and especially those marine mammals and seabirds depending on ice as haul-outs, but future scenarios are available for just a few emblematic species. Demographic models predict that changes in Antarctic sea ice will substantially reduce the abundance of global emperor penguin (*Aptenodytes forsteri*) by 2100 under a mid-range emission scenario (Jenouvrier *et al.*, 2014), even when complex dispersal processes are included (Jenouvrier *et al.*, 2017). A high probability of extinction is foreseen for the polar bear (*Ursus maritimus*) subpopulation of southern Beaufort under SRES A1B scenario by the end of the century, due to the decrease in the cover, the duration and the thickness of sea ice (Hunter *et al.*, 2010), but low probability of extinction has been attributed for all polar bears in the Arctic (Larsen *et al.*, 2014). However, a recent study showed that the high-energy requirements of polar bears could endanger their survival in extended ice-free periods (Pagano *et al.*, 2018).

Ocean acidification is another major stressor which will be enhanced in polar regions because of the higher capacity of seawater to absorb CO_2 at low temperatures, resulting in lower pH and under-saturated waters in aragonite and calcite (Hoegh-Guldberg *et al.*, 2014; Orr *et al.*, 2005). This may impact the growth and survival of calcifying shelled organisms such as Arctic pteropods, foraminifera in the Southern Ocean, and the recruitment of Antarctic krill *(Euphausia superba)*, all of those species being essential prey species at the basis of food-webs (Kawaguchi *et al.*, 2013; Larsen *et al.*, 2014; Trathan & Hill, 2016). Adding to the negative impacts of acidification, a combination of ice retreat and changes in primary production is projected to decrease Antarctic krill suitable habitat and survival rate (Piñones & Fedorov, 2016) with potential cascading effects on their many predators (Trathan & Hill, 2016).

4.2.2.3 Future impacts of fisheries exploitation on marine ecosystems

In addition to exposure to climate change, marine animal populations will likely undergo increased fishing pressure as a result of increasing demand for fish products (World Bank, 2013) particularly in the developing world (**Figure 4.2.6**; FAO, 2016). This will largely be driven by growth of human population that is projected to reach 9.8 billion people by 2050 (UNDESA, 2017) and by income growth in low- and middle-income countries (Vannuccini *et al.*, 2018). The rate of increase in demand for fish has been more than 2.5 per cent per year since 1950 and is likely to continue in the future (HLPE, 2014). The world fish production (capture and aquaculture) was projected to increase by 17% between the base period (2013-2015) and 2025 (FAO, 2016). With the growing demand, commercial fishing activities are likely to expand to all areas of the globe.

Scenarios that include governance in fisheries management, human consumption of seafood, and advancement of fishing technologies (Squires & Vestergaard, 2013) are starting to be integrated into global scale projections. For example, a simple surplus production model applied to a set of 4713 fisheries worldwide showed that a business-as-usual fisheries management scenario would increase the proportion of overexploited populations by ca. 30% in 2050 (Costello *et al.*, 2016). In contrast, in a scenario where long-term economic benefits are optimized, such as through rights-based fisheries management, the majority of exploited fish populations (98%) would recover to a healthy status, with a median time of recovery of about 10 years. Similarly, under the high emission scenario RCP8.5 and the SSP3 scenario (characterized by low economic development and a large increase in human population), maximizing the long term economic yield of the fishery was projected to increase the biomass of the skipjack tuna population (Dueri *et al.*, 2016). Recently, it was shown that reforming fisheries by adopting an optimal harvest policy that maximizes long-term economic benefits and that adapts its management strategy to climate-induced changes in fish biomass and spatial distribution could offset the detrimental impacts of climate change on future fish biomass and catch under most RCP greenhouse gas emission scenarios, except RCP8.5 (Gaines *et al.*,

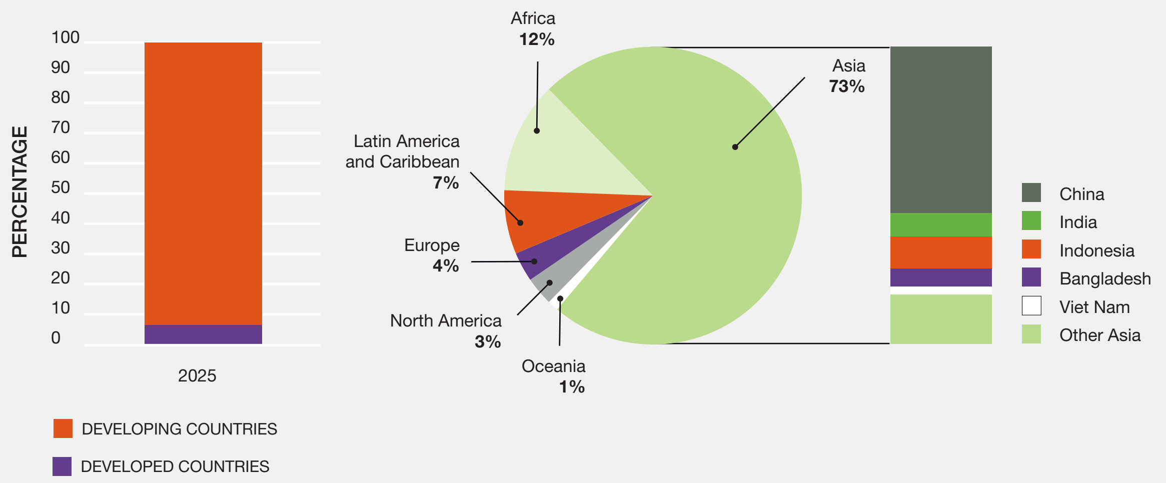


Figure 4 2 6 **Projections of additional fish consumed in 2025 (from fisheries and aquaculture) per world region.**

Developing countries are projected to eat 93 percent of the additional fish available for human consumption. Source: OECD and FAO (FAO, 2016).

2018). This important finding needs to be consolidated by further investigations in a context where fisheries maximum catch potential is projected to decrease by 2.8-5.3% and 7-12.1% by 2050 relative to 2000 under RCP2.6 and RCP8.5, respectively (Cheung *et al.*, 2018).

In addition to climate change (see 4.2.2.2.1), heavy fishing also impacts fish size, decreasing both the maximum size of species and the biomass of large-sized species because (i) high-value target species are generally larger, (ii) fishing gear is size-selective and often designed to remove larger fish, (iii) older and larger fish in a population become fewer as a result of accumulation of fishing mortality rate through time, and (iv) large species are more vulnerable because their life-history traits are generally linked to lower potential rates of increase (Shin *et al.*, 2005). Under heavy fishing, a SRES A1B climate change scenario was reported to magnify the reduction in fish size (Blanchard *et al.*, 2012). This shift towards smaller fish size and higher growth rates could ultimately increase the variability of fish biomass (Hsieh *et al.*, 2006).

Species targeted by fisheries are not the only species impacted by different fishing scenarios. Long-lived and vulnerable species such as marine mammals, turtles and birds suffer from direct impact of fish harvest though bycatch, and so their future is tightly linked to the long-term fishing strategies adopted. The interaction with climate change is complex to resolve but some studies have started addressing the potential synergistic effects. Some models based on species distribution projected that climate change will alter the future distribution of both fisheries and seabird populations, altering the rates of future bycatch and hence seabird mortality rates (Krüger *et al.*, 2018). For some species, spatial overlap with fisheries may decline, reducing rates of incidental mortality associated with human activity. However, for two highly threatened seabird species (grey-headed and wandering albatross), severe range reductions and increased overlap with fisheries are projected.

In addition to scenarios of fishing management, the future status of wild fish populations cannot be envisaged without considering alternative scenarios of aquaculture development which will play a major role in sustaining the supply of seafood products and the maintenance of per capita fish consumption (Delgado *et al.*, 2003; FAO *et al.*, 2018). But the development of aquaculture is partly dependent upon the exploitation of low trophic level fish species which supply fishmeal for farmed fish.

Aquaculture development could potentially reduce fishing pressure on wild fish populations, but not to an extent that could compensate for projections of increases in demand for seafood products and fishing technology, both of which result in increased fishing pressure (Quaas *et al.*, 2016). Taking into account projections in human population, climate change (IPCC A1B scenario), and technological development in aquaculture, a bio-economic model projected that if fishmeal prices increase, this would encourage fishers to maximize their short-term economic profits and exceed yearly quotas, leading to collapse of exploited fish populations (Merino *et al.*, 2012). Given the current increasing trends of fishmeal prices (Merino *et al.*, 2010), this implies that compliance to strict fisheries management and market stabilization measures need to be seriously considered to maintain exploited populations at sustainable levels. Likewise, another bio-economic model run under contrasted archetype scenarios suggested that relative to climate change impacts, fisheries regulation is the most important factor in determining the future of fish populations (Mullon *et al.*, 2016). However, the interplay between drivers of change cannot be ignored in fisheries management strategies (see example in **Box 4.2.3**). A multi-model ensemble approach allowed to show that the risk of negative synergistic effects between changes in primary production and in fishing effort was higher for small forage fish species (Fu *et al.*, 2018).

Box 4 2 3 Synergistic impacts of multiple drivers on tropical coral reefs.

Tropical coral reefs share a history of strong dependence on natural and human systems (Maire *et al.*, 2016) that must be accounted for in attempts to maintain long-term human development and well-being, and marine biodiversity (Cinner *et al.*, 2016). Indeed, coral reefs support the nutritional and economic needs of people in many developing countries. Their exceptional biodiversity translates directly into biomass production and thus food security (Duffy *et al.*, 2016). However, coral reefs face multiple and considerable challenges from ocean warming (see 4.2.2.2.2), ocean acidification, pollution, overexploitation and destructive fishing practices. More than 80% of the world's coral reefs are severely over-fished or have degraded habitats, thus imperiling the livelihood and sustenance of coastal human populations (McClanahan *et al.*, 2015). This negative spiral is likely to accelerate in the future due to the synergistic effects of climate change and direct human impacts. For example, nutrient loads from the land increases the vulnerability of corals to bleaching (Vega Thurber *et al.*, 2014). Plastic debris were estimated to increase coral susceptibility to diseases from 4% to 89% with structurally complex corals being eight times more likely to be affected by plastic (Lamb *et al.*, 2018) inducing a loss of fish productivity (Rogers *et al.*, 2014). Tipping points exist at which coral reef ecosystems can shift to being dominated by macroalgae (Holbrook *et al.*, 2016), with low resilience, reductions in biodiversity and degradation of the many ecosystem services they provide, such as reef-associated fisheries and tourism. However, there are opportunities for improving the status of coral reefs by the combined action of reducing both greenhouse gas emissions and overfishing of species which help the recovery of coral reefs by grazing their algal competitors (**Figure 4.2.7**; Kennedy *et al.*, 2013). Robust, integrated models that can account for combinations of multiple impacting drivers are still lacking, but these are needed to simulate the dynamics of coral reef social-ecological systems on a long-term basis and better anticipate their futures. This challenge is even more difficult given the multispecies nature of fisheries, the complexity of trophic interactions, and the time scales on which different processes determine the trajectories of coral reef social-ecological systems and the boundaries beyond which they collapse.

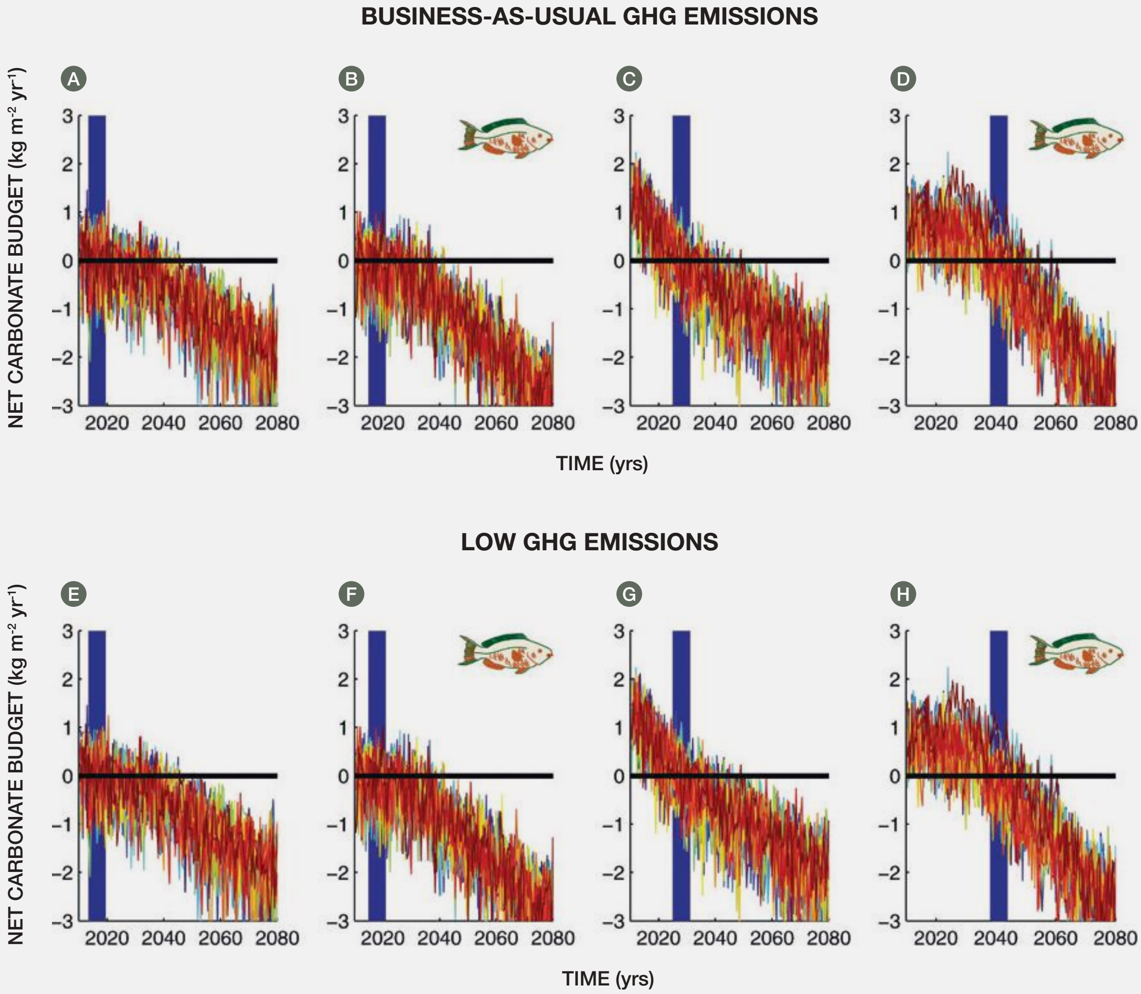


Figure 4 2 7 **Future carbonate budgets (proxy for net production of corals skeletons) of Caribbean coral reefs under climate change and acidification scenarios (top panel: high RCP8.5 greenhouse gas emission scenario, bottom panel: strong mitigation RCP2.6 emission scenario), without or with local conservation of grazing fish (parrot fish symbol in B, D, G, H).**

Initial conditions of reefs are either degraded with 10% coral cover (A, B, E, F) or healthier with 20% coral (C, D, G, H). Vertical blue bars indicate point at which the projected budget becomes negative (erosion of corals skeleton exceeds production). Source: Kennedy *et al.* (2013).

4.2.2.4 Future impacts of pollution on marine ecosystems

4.2.2.4.1 Persistent organic pollutants and plastics: another 'Silent Spring'?

Over the last century the human enterprise has fundamentally altered the planet by releasing large quantities of persistent organic pollutants (POPs) into the environment. These synthetic organic compounds have harmful and toxic properties and are not readily metabolized by bacteria or other life forms, thus prolonging their presence in the environment. Concerns about their effects on wildlife and people were first raised by Rachel Carson's book 'Silent Spring' (Carson, 1962), highlighting the devastating effects of organochlorine POPs on birds and aquatic animals in particular. As a result, many POPs were tightly regulated or banned under the Stockholm Convention (UNEP, 2001), and their production has ceased or decreased for most listed substances. Large historical burdens of these pollutants still circulate in the environment however (Harrad, 2009), and novel substances get synthesized at a rapid pace, with potentially harmful effects.

Synthetic organic polymers (plastics) form another class of pollutants that share certain properties with POPS in that they persist and accumulate in the environment, can be transported over long distances (reaching remote polar regions for example; Science for Environment Policy, 2017), and can have harmful effects on wildlife and people. In contrast to POPs, their production numbers are much higher overall and still increasing, thus global concerns about plastic pollution now match or exceed those for other POPs, particularly with respect to the marine environment which forms a sink for discarded plastic waste (Jambeck *et al.*, 2015; Worm *et al.*, 2017). Annual plastic production now exceeds 330 million metric tons (Mt) (PlasticsEurope, 2015), with a cumulative burden of 8300 Mt produced since 1950 (Geyer *et al.*, 2017), approximately 6300 Mt of which has been discarded (9% recycled, 12% incinerated, and 79% ended in landfills or the natural environment). If current production and waste management trends continue, roughly 12,000 Mt (million tons) of plastic waste will be in landfills or in the natural environment by 2050 **(Figure 4.2.8)**. If evenly spread around the globe, this would equal a burden of ~24 tons of plastic waste for each square kilometre of land and sea surface. This level of pollution in terms of volume and persistence has no previous analogue in human history.

Negative impacts on the planet and people are becoming more profound **(Figure 4.2.9)** as exposure to plastic pollutants intensifies. As an example, about 90% of seabirds examined today have plastic in their gut, with

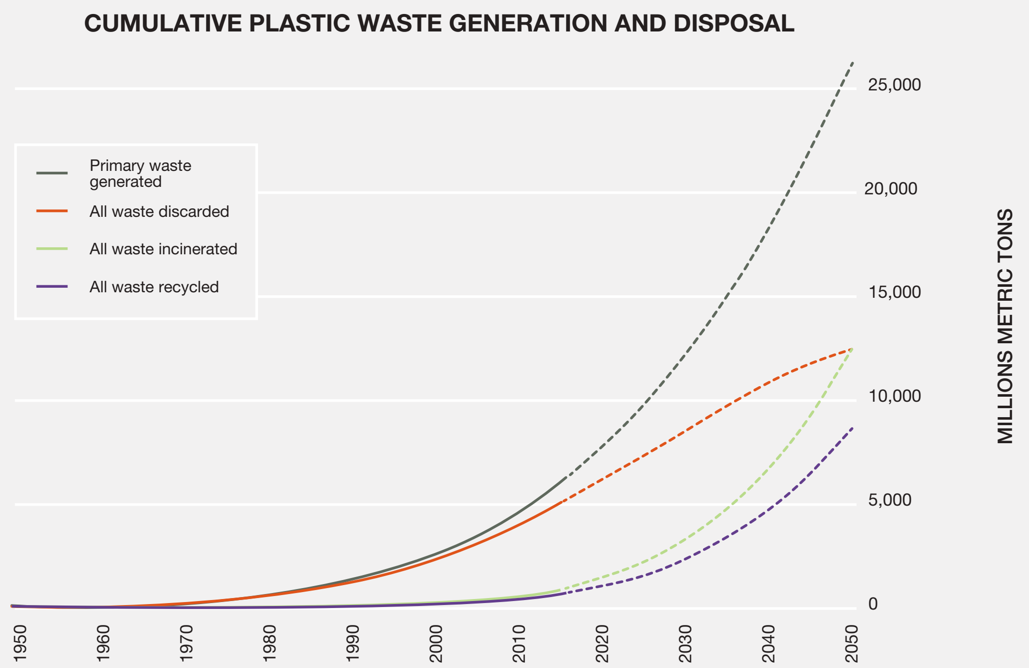


Figure 4 2 8 **Current global trends and likely future trajectories of total plastic waste generation and management.**

After data in Geyer *et al.* (2017).

100% expected to be exposed by 2050 (Wilcox *et al.*, 2015). Sea turtles are similarly affected (Schuyler *et al.*, 2015), as are at least 693 other marine species that have been recorded to be compromised by plastic pollution (CBD, 2016). Much of the plastic is released as or broken down into small microplastic (1 µm-1mm) or nanoplastic (<1µm) particles. While the harmful effects of microplastic debris are well understood, the long-term effects of the smallest fragments are only now emerging (Galloway & Lewis, 2016), including their tendency to interact with other pollutants (GESAMP, 2015), facilitate diseases (Lamb *et al.*, 2018), and transmit through the food chain **(Figure 4.2.9)**.

Clearly, another 'Silent spring' scenario seems plausible, if effects on numerous wildlife species continue to accelerate further. Because plastic persists and accumulates in the environment in similar ways POPs do, a zero-net-release policy that builds upon the successful Stockholm Convention (SC) on Persistent Organic Pollutants (POPs) may be a promising strategy to mitigate the risk posed by current and future levels of plastic pollution. Yet, in contrast to traditional POPs, which are largely emitted by industry, plastic pollution touches every person's life, and requires a broader societal effort including designers, producers, regulators, and consumers of plastic products to engage in comprehensive solutions (GESAMP, 2015; Worm *et al.*, 2017).

4.2.2.4.2 Nutrient loads and eutrophication

Numerous model projections show that coastal zones in many world regions are almost certain to see increases in nitrogen (N) and phosphorus (P) from increasing river loads in the coming decades (Sutton *et al.*, 2013; **Figure 4.2.10**). In contrast, silica (Si) river export is decreasing globally as a result of retention in the increasing number of reservoirs in the world's river systems and this trend will also continue in many parts of the world. The result of these simultaneous changes of N, P and Si will continue to alter nutrient stoichiometry, affecting not only total algal growth but also biodiversity in coastal waters, including the propensity for harmful algal blooms (HABs). The enhanced primary production in coastal surface waters can cause eutrophication, with subsequent sinking of excess degradable organic matter to bottom waters where aerobic microbial decomposition reduces oxygen concentration. The decline in oxygen concentrations due to nutrient loads in coastal waters will likely be exacerbated with climate change, due to decreased oxygen solubility in warmer waters and decreased oxygen transport to deeper waters because of stronger stratification of the water column (Breitburg *et al.*, 2018). The expansion of areas of low oxygen will impact marine biodiversity at all levels from individuals' physiology and behavior, to populations' demography and range shifts with consequences for

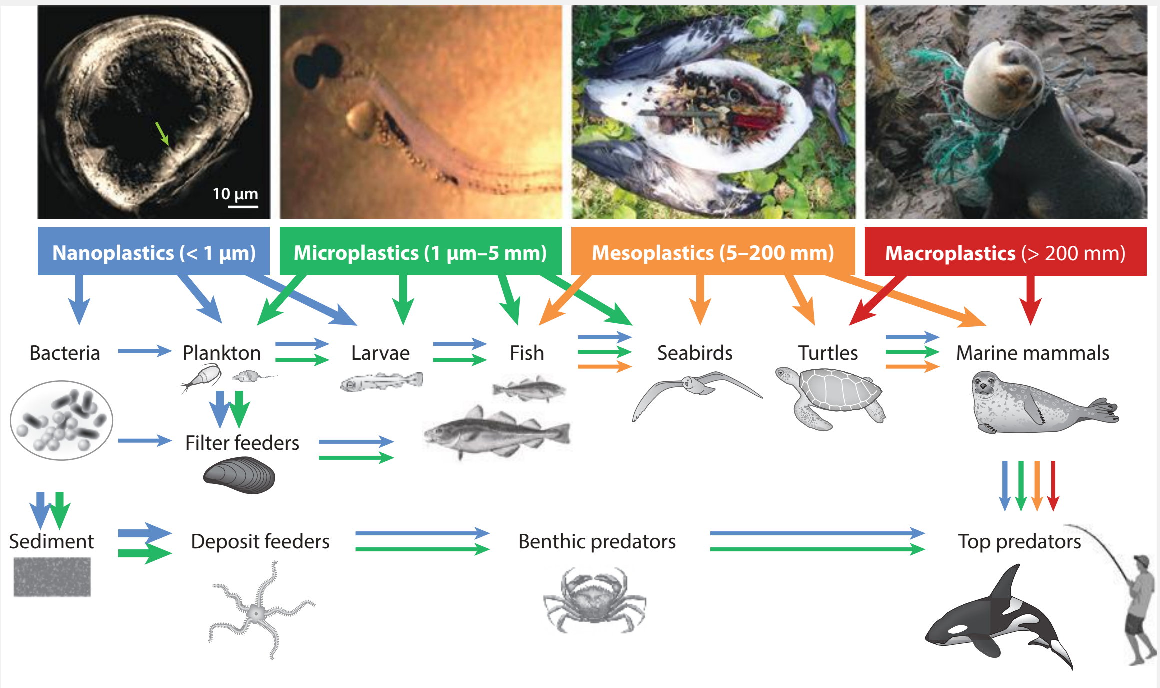


Figure 4 2 9 **Possible pathways by which plastic pollutants of different size classes enter the food chain and propagate to higher trophic levels, including humans.**

After Worm *et al.* (2017).

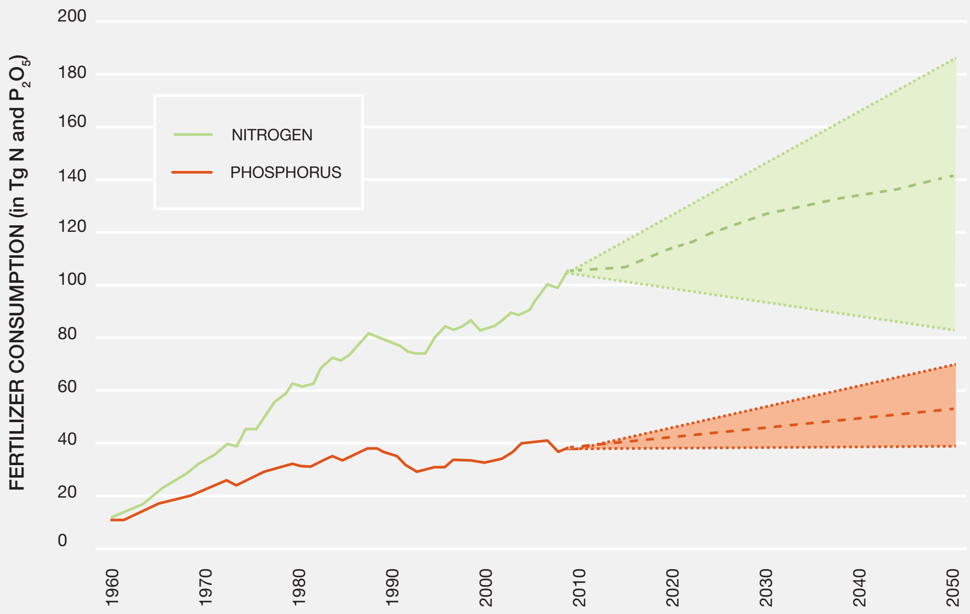


Figure 4 2 10 **Trends in global mineral fertilizer consumption for nitrogen and phosphorus and projected possible futures.**

Source: Sutton *et al.*, 2013.

species assemblages and food-webs (Levin *et al.*, 2009; Pörtner *et al.*, 2014).

Storylines developed by the IPCC and the Millennium Ecosystem Assessment and translated into changes of the main anthropogenic drivers, i.e. economic development, demography and land use (Alcamo *et al.*, 2007), have been applied to project conditions to 2050. Although each storyline has different assumptions, they show major increases in N and P river export especially in South and Eastern Asia, in South America and Africa where fertilizer use will likely increase to support the population, and where urbanization and lagging treatment of wastewater and sewage connection will lead to increasing nutrient discharge to surface water (e.g., Glibert *et al.*, 2018). In contrast, stabilized or decreasing trends in nutrient loads are projected in Europe, North America and Australia owing to the development of improved wastewater treatment systems, and improved nutrient management reducing NH_3 volatilization, leaching and run-off. In these regions, improvements in hypoxia and frequency or magnitude of HABs may be realized.

However, the trajectory of nutrient loads is additive with other global changes, such as temperature rise, which will alter stratification of the water column, availability of nutrients and their forms and ratios, and pCO2, among other factors (e.g., Boyd & Doney, 2003). Recent models supported evidence for increased eutrophication together with climate changes, and therefore the propensity for the worsening of HABs and/or hypoxia by the end of the century (Sinha *et al.*, 2017). Multiple combined changes such as increases in nutrient pollution, in global temperature and in reservoir capacity resulting in increased retentiveness of rivers, require proactive management to stabilize or reduce the impacts of eutrophication, including hypoxia and the frequency of HABs.

4.2.2.5 Future impacts of coastal development on marine ecosystems

Direct human-related drivers of change such as urbanization, coastal development, and land-use change will bring challenges to coastal ecosystems in addition to climate change. Coastal populations are increasing disproportionately relative to the global population increase. Many of emerging cities are on the coast and their growth will add to the 75% of the world's mega-cities which are already coastally located (World Economic Forum's Ocean Programme, 2017). Over 2.6 billion people live on or near the coast, many in developing countries where dependence on coastal resources may be high and demand for multiple benefits such as food, coastal protection and income, will continue to grow as human populations expand (Bell *et al.*, 2009; Sale *et al.*, 2014). Some 1.36 billion live on tropical coasts, and this is projected to grow to 1.95 billion by 2050, with associated pollution and eutrophication of coastal waters and degradation of coastal ecosystems (Sale *et al.*, 2014). Urbanization and coastal development can restrict the capacity of coastal ecosystems to adapt to rising sea levels e.g. through the "coastal squeeze" (Wong *et al.*, 2014). Along urbanized coastlines, the resilience of wetlands to SLR will depend on the availability of accommodation space (Schuerch *et al.*, 2018) and sediment supply (Lovelock *et al.*, 2015) which are reduced by anthropogenic infrastructure barriers (e.g., flood protection structures, roads, settlements). Future expansion of coastal development will also bring risks to iconic and threatened species. For example, the expansion of artificial lighting at night from coastal development interrupts the sea-finding behaviour of sea turtle hatchlings and ultimately survivorship (Gaston & Bennie, 2014; Kamrowski *et al.*, 2014).

Future projections show a multiplicity of human stressors acting simultaneously with direct climate-induced changes on social-ecological systems. Stressors from population growth and coastal development such as nutrient run-off, urbanization, and land-use change are expected to increase and combine with climate stressors such as sea level rise and warming to exacerbate risks for rocky and sandy shores, and seagrasses **(Box 4.2.4)**. Models show that mangroves are particularly threatened by projected coastal development, with the main direct drivers including the expansion of aquaculture (prevalent in both Asia and Latin America) and agriculture (mostly rice cultivation and pasture), extraction of timber and related forest products (e.g., for charcoal and domestic construction), and infrastructure development and alterations of freshwater flows (e.g., for due to settlements, transportation networks or dams) (Roy Chowdhury *et al.*, 2017). Under projected changes, coastal adaptation options will involve increasingly difficult trade-offs in future among multiple development and biodiversity objectives (Mills *et al.*, 2015).

4.2.3 Freshwater ecosystems

4.2.3.1 Freshwater biodiversity and current threats

Freshwater ecosystems provide fundamental services to humans such as food, water, nutrient retention, recreation, and climate regulation. Globally, freshwaters (i.e. rivers, lakes, wetlands) represent less than 0.02% of Earth's water volume and cover only about 0.8% of Earth's surface (Dawson & Dawson, 2012). However, an estimated 129,000 species live in freshwater ecosystems, representing ~8% of Earth's described species (Balian *et al.*, 2008; **Figure 4.2.11**). The relative contribution of freshwater ecosystems to global biodiversity is thus extremely high (Tedesco *et al.*, 2017; Wiens, 2016). Climate, productivity and area size drive freshwater diversity patterns globally despite profound functional differences between taxa (Moomaw *et al.*, 2018; Tisseuil *et al.*, 2013).

Box 4 2 4 Synergistic impacts of multiple pressures on seagrass meadows.

Direct human-related drivers of change such as urbanization, coastal development, and land-use change will bring challenges to coastal ecosystems. For seagrasses, key threats include sediment and nutrient run-off from upstream land-use change, physical disturbance, algal blooms, and invasive species, as well as climate warming and disease (Orth *et al.*, 2006; Waycott *et al.*, 2009). Requirements for clear water and low nutrient concentrations make seagrasses vulnerable to eutrophication, as nutrient and sediment loading reduce light availability and favor faster-growing algae (Burkholder *et al.*, 2007; Duffy *et al.*, 2013). The protected embayments in which seagrasses grow best are also prime real estate for coastal and harbor development. As a result seagrasses are declining worldwide, and roughly 30% of global seagrass cover has been lost since the first estimates were made in the late 19th century, with loss rates increasing in recent decades (Waycott *et al.*, 2009). Ten of the 72 known seagrass species on earth are at elevated risk of extinction and three species are classified as Endangered (Short *et al.*, 2011).

Perennial organisms such as seagrasses are vulnerable to human disturbance and, under repeated impacts, often yield dominance to faster growing, opportunistic species such as fleshy and filamentous algae. In the Baltic Sea, for example, dominance by eelgrass and rockweed has yielded over recent decades to accumulations of ephemeral algae (Bonsdorff *et al.*, 1997). Long-term field monitoring suggests that exploitation of piscivores such as cod in offshore waters has released the smaller inshore fishes—mesopredators—from top-down control, and their consumption of grazing invertebrates indirectly led to algal blooms and decline of perennial seagrasses (Eriksson *et al.*, 2011). Coastal vegetation, including seagrasses, protects coastal human communities against storm damage, and the continuing decline of these natural barriers will likely be aggravated by SLR. Coastal habitat loss exacerbates damage from storms and flooding in coastal communities (Gedan *et al.*, 2011). Mapping the risk of such hazards along the coastline of the USA shows that, under several projected climate scenarios, the number of people, especially the poor and elderly, and the total value of residential property exposed to hazards could be reduced by half by preserving existing coastal habitats (Arkema *et al.*, 2013).

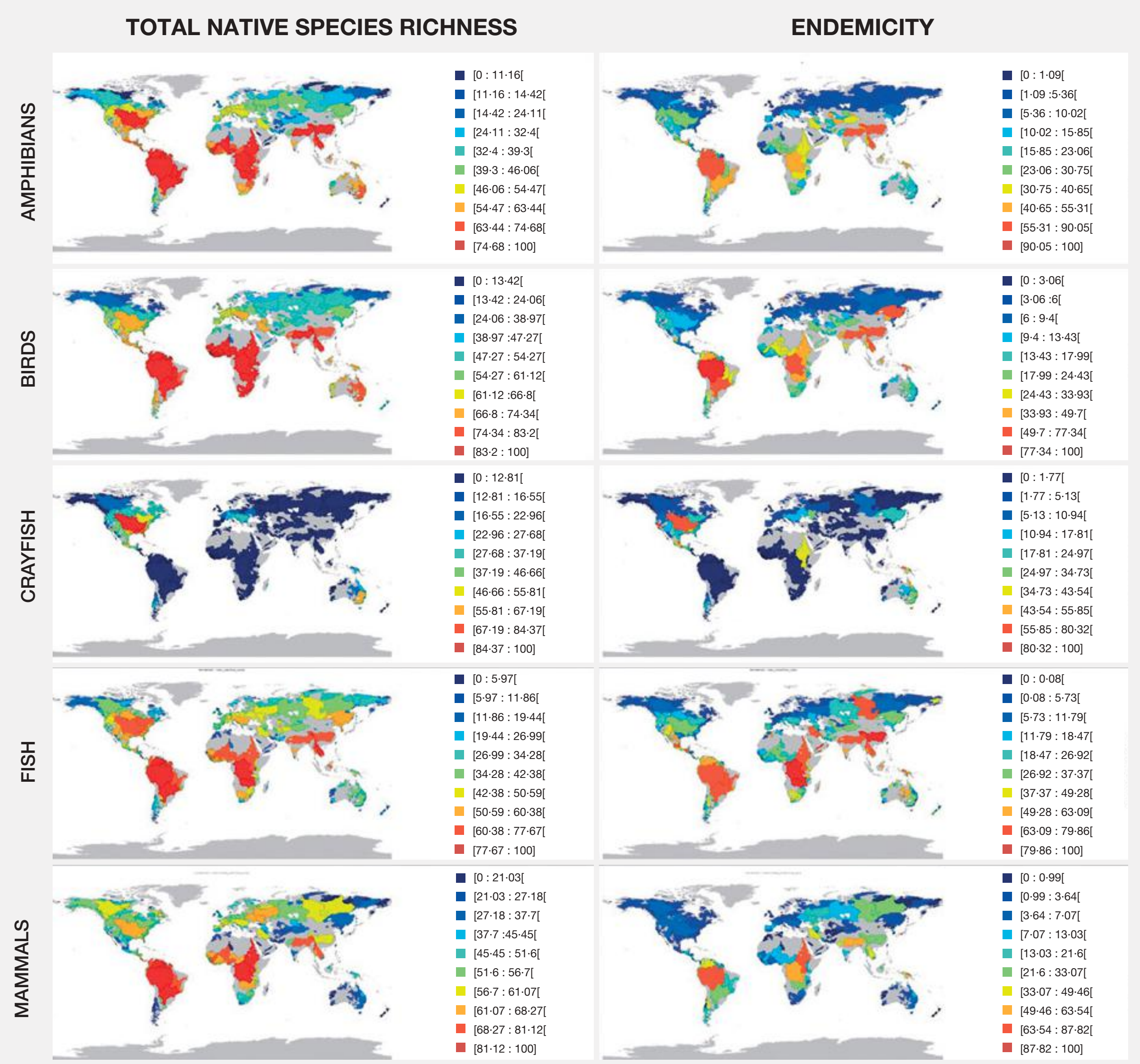


Figure 4 2 11 **Global diversity maps (species richness and endemicity) for freshwater fishes, aquatic amphibians, aquatic mammals, crayfish and aquatic birds.**

For comparison purpose, the diversity descriptor values of each taxon are rescaled between 0 and 100. Study based on the global distributions of 13, 413 freshwater species among five taxonomic groups (i.e. 462 crayfish, 3263 amphibians, 8870 fish, 699 birds and 119 mammals) and conducted on 819 river drainage basins covering nearly 80% of Earth's surface. After Tisseuil *et al.* (2013).

Current major threats to freshwater biodiversity include climate change, habitat modification and pollution from land-use, habitat fragmentation and flow regime homogenization by dams, non-native species, increased eutrophication resulting from nutrient and organic discharges, water abstraction, and overexploitation (Young *et al.*, 2016). Those threats currently affect freshwater biodiversity and functioning to varying degrees (Carpenter *et al.*, 2011; Vörösmarty *et al.*, 2010), and their additive and potentially synergistic effects may further threaten future freshwater biodiversity and resources (Collen *et al.*, 2014; Knouft & Ficklin, 2017).

4.2.3.2 Future climate change impacts on freshwater biodiversity and ecosystem functioning

The lowest greenhouse gas emissions scenario is the only scenario not expected to threaten much of global freshwater biodiversity in 2050 through direct effects of climate change. Under all other scenarios, freshwater biodiversity is expected to decrease proportionally to the degree of warming and precipitation alteration. All water body types on all continents are likely to be affected. Warmer waters will alter community structure, food webs, body sizes, and species ranges — especially in regions where semi-arid and Mediterranean climates currently occur as well as high-mountain ecosystems. In addition to reduced biodiversity and ecosystem functioning, warmer and less water will lead to species extinctions because of habitat shrinkage.

Scenarios of climate change impacts on global freshwater ecosystem biodiversity and functioning were reviewed by Settele *et al.* (2014). Climate change alters freshwater ecosystems and their biodiversity by changing (1) temperatures, (2) water availability and (3) flow regimes through changes in precipitation (Döll & Zhang, 2010; Knouft & Ficklin, 2017) and/or temperature (Blöschl *et al.*, 2017). Increased water temperatures often lead to progressive shifts in the structure and composition of assemblages because of changes in species metabolic rates, body size, migration timing, recruitment, range size and interactions (Daufresne *et al.*, 2009; Myers *et al.*, 2017; Parmesan, 2006; Pecl *et al.*, 2017; Rosenzweig *et al.*, 2008; Scheffers *et al.*, 2016). There is already evidence of regional and continental shifts in freshwater organism distributions following their thermal niches (Comte *et al.*, 2013), local extirpations through range contractions at the warm edges of species' ranges (Wiens, 2016), and body size reductions (Daufresne *et al.*, 2009). Warmer water temperatures also enhance microorganism metabolism and processing of organic matter (unless dissolved oxygen is limiting), causing eutrophication when nutrient levels are high (Carpenter *et al.*, 2011; Mantyka-Pringle *et al.*, 2014) as well as increased omnivory. Warming also induces phenological mismatches between consumers and resources in highly seasonal environments, potentially destabilizing food-web structure (Woodward *et al.*, 2010a).

The strongest temperature increases are projected for eastern North America (0.7 to 1.2 °C under RCP2.6 and RCP8.5, respectively, by 2050), Europe (0.8 to 1.2 °C), Asia (0.6 to 1.2°C), southern Africa (>2.0°C under RCP8.5) (van Vliet *et al.*, 2016b) and Australia (CSIRO & Bureau of Meteorology, 2015). Moderate water temperature increases (<1.0°C) by 2050 are predicted for South America and Central Africa (Van Vliet *et al.*, 2013; van Vliet *et al.*, 2016b). Changes in water temperature are projected to lead to local or regional population extinctions for cold-water species because of range shrinking especially under the RCP 4.5, 6.0 and 8.5 scenarios (Comte & Olden, 2017). Most lowland-tropical freshwater species are expected to tolerate warmer conditions where water is sufficient (Comte & Olden, 2017).

Decreased water availability and altered flow regimes reduce habitat size and heterogeneity. This increases population extinction rates because the probability of species extinctions increases with reduced habitat size (Tedesco *et al.*, 2013). Climate change can also alter flow regime seasonality and variability (e.g., Blöschl *et al.*, 2017; Döll & Zhang, 2010) and increase flow intermittency (Pyne & Poff, 2017). This would lead to decreased food chain lengths through loss of large-bodied top predators (Sabo *et al.*, 2010), altered nutrient loading and water quality (Woodward *et al.*, 2010b), and/or pushing taxa into novel trajectories from which they may not recover (Bogan & Lytle, 2011). However, whatever the RCP scenario, climate change impacts on the timing of seasonal streamflow are found to be generally small globally (Eisner *et al.*, 2017). Yet, relative to water availability and according to the wet-wetter/dry-dryer mechanism (Gudmundsson *et al.*, 2017; Held & Soden, 2006; Wang *et al.*, 2017), more severe water stress in current drylands is expected in the future. Although under RCP2.6 the distributions of water availability may change little by the end of the 21st century, RCP4.5, 6 and 8.5 scenarios are expected to induce substantial shrinking of water drainage where semi-arid and Mediterranean climates currently occur. Reduced water availability in those regions, including shifts from permanence to intermittency, will generate population extirpations of all types of freshwater organisms (Jaeger *et al.*, 2014), leading to global net biodiversity losses because endemism is usually high in those regions. For example, projected fish extinction rates from drainage shrinking under the high emission SRES A2 scenario in river basins worldwide show that among the 10% most-altered basins, water availability loss is likely to increase background extinction rates by 18.2 times in 2090 (Tedesco *et al.*, 2013; **Figure 4.2.12**). Also, in glacier-fed high-mountain ecosystems, significant changes to snow and glacier melt regimes, including glacier disappearance, have already been observed (Leadley *et al.*, 2014) and are expected to continue (Kraaijenbrink *et al.*, 2017). This leads to reduced water availability and declines in biodiversity through local population extirpations and species extinctions in regions of high endemicity in all water body types. Besides biodiversity losses, losses of glacial ice in closed drainages and flows in semi-arid regions (Vörösmarty *et al.*, 2010) will substantially decrease water for agriculture, power and public water supply, thereby increasing economic vulnerability in the affected regions (e.g., Moon, 2017).

Wetlands, including peatland and permafrost regions, sequester carbon in their soils. But when confronted to warming, drying and conversions to agriculture, wetlands are expected to release CO_2, CH_4, and N_2O. Global warming alone is projected to contribute 1.6 x 10^8 kilotons of carbon from melting permafrost to the atmosphere and CH_4 emissions from freshwater wetlands are projected to nearly double by 2100 (Moomaw *et al.*, 2018). Such changes are very likely to impact biodiversity negatively due to habitat loss and reduced water quality, which increase the risk of extinctions and extirpations of wetland endemic and dependent species (Segan *et al.*, 2016).

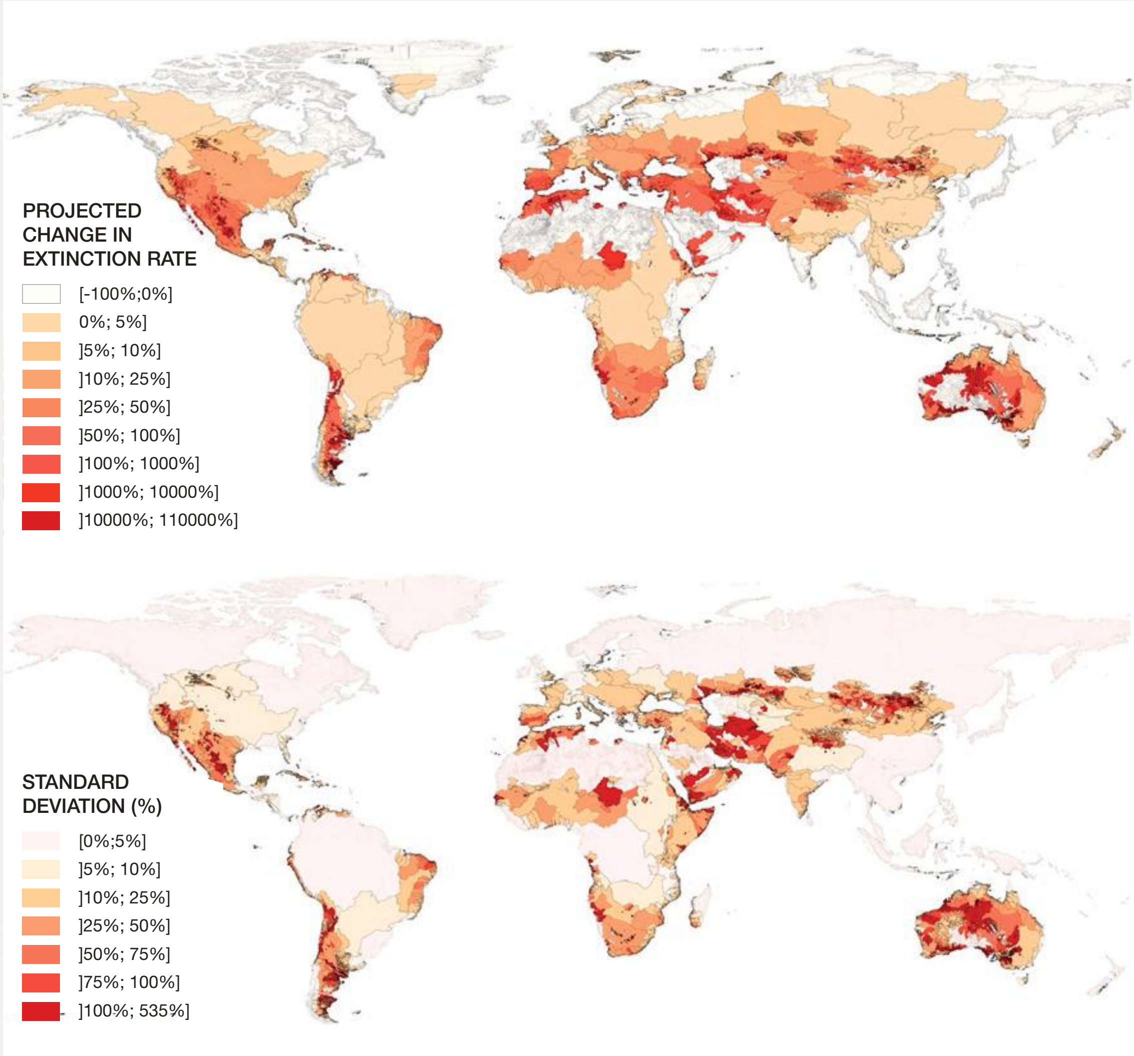


Figure 4 2 12 **Global patterns of proportional increase or decrease in freshwater fish extinction rates between current climatic conditions and future (2090) under the most 'pessimistic' IPCC SRES scenario (A2).**

Negative values of projected change in extinction rate depict drainage basins where extinction rates may decrease, while positive values depict drainage basins where extinction rates may increase. 91 949 river drainage basins covering ~99% of the terrestrial surface. After Tedesco *et al.* (2013).

4.2.3.3 Future land-use change impacts on freshwater biodiversity and ecosystem functioning

Land use will likely increase the risk of eutrophication, leading to local population extinctions, changes in community structure and consequent modification of the food-web, ecosystem temporal instability, and establishment and spread of pathogens and toxic cyanobacteria blooms globally. Land use will become especially problematic in the emerging tropical economies because of increased human population density and weak pollution controls. Increasing pollution and eutrophication will degrade water quality, impair biological resource availability, reduce nutrition in developing countries, and reduce recreational opportunities and tourism income. Globally increased toxic cyanobacteria blooms and pathogens will increase health risks for people and livestock. These risks will most affect closed water bodies and estuaries, but rivers will also be threatened. The additional impact of future increasing use of pesticides in agriculture is hard to quantify due to a lack of scenario studies.

Land use, especially croplands, mining and urbanization, will affect freshwater ecosystems and associated biodiversity through two main pathways. First, further increased water and groundwater withdrawals are expected to decrease habitat (water) availability for freshwater organisms leading to increased population extinction rates in rivers and lakes or direct extinctions from wetland conversions (Gardner *et al.*, 2015; Tilman *et al.*, 2001). The problem is exacerbated in semi-arid regions where water withdrawals lead to some rivers and lakes drying routinely, with ensuing species extinctions (Foley *et al.*, 2005). Second, water quality is usually degraded by land use, and this trend is likely to continue. Intensive agriculture increases sediment, nutrient and pesticide loads to ground and surface waters (Lotze *et al.*, 2006; Vasconcelos *et al.*, 2017). The continuing, rapid urbanization also will substantially degrade water quality in many regions mostly through organic or phosphorous loadings, especially where wastewater treatment is absent. Mining leads to increased loadings of toxic metals, salts and acids (Daniel *et al.*, 2015; Hughes *et al.*, 2016). Such pollutants induce direct local mortality, impaired individual development and health, and altered community structure (Muturi *et al.*, 2017), particularly for predators through bioaccumulation (Carpenter *et al.*, 2011). Since nutrient loadings progressively lead to increased eutrophication, oxygen depletion, animal mortality, extirpation of submerged macrophytes and the production of algal blooms (including toxic varieties of cyanobacteria) (Foley *et al.*, 2005; Paerl & Paul, 2012), efforts to wastewater treatment related to all anthropogenic activities will need to increase. Pollutants affect in particular the biodiversity and functioning of closed systems and estuaries (Lotze *et al.*, 2006). For example, urban point sources have been the leading cause of hypoxia across European lakes since 1850 (Jenny *et al.*, 2016). Furthermore, continued deforestation, a key component of land-use change, will further disrupt organic matter processing and food webs, exacerbating the establishment and spread of pests and pathogens, especially in tropical regions (Morris *et al.*, 2016).

Future scenarios of changes in cropland area, pasture, forest and other natural land diverge widely depending on the underlying socio-economic assumptions (see sections 4.1 and 4.2.4) (Alexander *et al.*, 2017c; Popp *et al.*, 2017; van Vuuren *et al.*, 2011). For the RCP4.5 scenario, a decrease of cropland and pasture was projected in one study (van Vuuren *et al.*, 2011), which is expected to minimize future freshwater biodiversity disturbances. However, the global scenarios mask regional dissimilarities. For example, projections of future primary vegetation show major decreases in western and middle Asia (RCPs 2.6, 6.0 and 8.5), Australia (only RCP2.6) and North America (only RCP 8.5) (Settele *et al.*, 2014).

Water pollution has been considerably reduced in Australia, North America and Western Europe (Vörösmarty *et al.*, 2010), except for pharmaceuticals, biocides and plastics because of ineffective treatment (Ebele *et al.*, 2017). Reduced water pollution will benefit freshwater biodiversity. However, Sinha *et al.* (2017) projected increased eutrophication induced by increased precipitation from climate change in some regions, and Oliver *et al.* (2017) projected no decrease in nitrogen and phosphorus concentrations for most USA lakes despite attempts to reduce diffuse pollution. If there is little technology transfer to developing countries, then water pollution may increasingly threaten freshwater ecosystems, particularly in tropical regions because of increased human density notably in Asia and Africa, that are expected to account for over half of global population growth between 2015 and 2050 (UNDESA, 2015). Under RCP2.6, if much agricultural, mineral and bioenergy production relocates from high-income to low-income regions, pollution, freshwater biodiversity and aquatic ecosystem functioning will further worsen in those regions.

4.2.3.4 Future impacts of habitat fragmentation on freshwater biodiversity and ecosystem functioning

Hydropower is expected to increase worldwide whatever the RCP scenario unless other renewable energy sources are installed. Regions where significant losses in streamflow and decreased capacity production are projected, or where human population is expected to continue to increase (such as in many countries of Africa), should be most affected. Fragmentation of rivers by dams increases species extinction risks by blocking spawning/rearing migrations and/or reducing population sizes and gene flow.

Hydropower infrastructures alter rivers, floodplain lakes, wetlands and estuaries. Dams transform river basins by creating artificial lakes locally, fragmenting river networks, and greatly distorting natural patterns of sediment transport and seasonal variations in water temperatures and flows (Latrubesse *et al.*, 2017). Altered flow seasonality in rivers has led to less diverse fish assemblages, decreased inland fisheries production, less stable bird populations and lower riparian forest production (Jardine *et al.*, 2015; Kingsford *et al.*, 2017; Sabo *et al.*, 2017). Sediment retention by dams leads to delta recession (Luo *et al.*, 2017), decreased coastal fisheries catches, and degraded tropical mangrove forests that are major carbon sinks (Atwood *et al.*, 2017).

Dams also prevent upstream-downstream movement of freshwater animals, facilitate settlement of non-native species, cause local species extirpations and replacements and increase risk of water-borne diseases in reservoirs and highly altered environments by modifying productivity (Fenwick, 2006; LeRoy Poff & Schmidt, 2016). Dams have also caused a significant displacement of IPLCs around the world and projected expansion of dams, as shown in **Figure 4.2.13**, suggest significant overlap with areas held and/or managed by IPLCs (Garnett *et al.*, 2018). The fragmentation of river corridors also reduces population sizes and gene flows of aquatic species, increasing species extinction risks (Cohen *et al.*, 2016; Dias *et al.*, 2017). Dams are mainly concentrated in highly industrialized regions, but future hydropower development will be concentrated in developing countries and emerging economies (Grill *et al.*, 2015; Zarfl *et al.*, 2015). Hydropower is expected to expand worldwide whatever the RCP scenario **(Figure 4.2.13)**. Most hydropower plants are currently situated in regions where considerable declines in streamflow are projected, resulting in mean reductions in usable hydropower capacity (Turner *et al.*, 2017; van Vliet *et al.*, 2016b). Those regions may increase dam building to compensate for the losses unless other energy options are implemented (Zarfl *et al.*, 2015). Also, growing population density is expected to also increase demands for hydropower globally, especially in tropical regions (Winemiller *et al.*, 2016) where freshwater biodiversity is concentrated (Tisseuil *et al.*, 2013; UNDP, 2016).

4.2.3.5 Future impacts of non-native species on freshwater biodiversity and functioning

Future threats to freshwater ecosystems from non-native species will be greater in emerging economies because of accelerated economic growth, whatever the scenario. Non-native species often compete with and prey upon native species, generating occasional local population extirpations (Carpenter *et al.*, 2011), altering ecosystem structure and function (e.g., Blanchet *et al.*, 2010; Toussaint *et al.*, 2018), spreading infectious diseases (Gagne *et al.*, 2018) and sometimes degrading ecosystem services and economies (Leung *et al.*, 2002). They are a key contributor to biotic homogenization of aquatic ecosystems globally (Rahel, 2007; Villeger *et al.*, 2011). Anthropogenic disturbances coupled with introductions of non-native fish (particularly piscivores) are associated with native species extirpations and range reductions, especially in lakes and reservoirs (Whittier & Kincaid, 1999), as well as rivers (Hughes & Herlihy, 2012). In addition, reduced ecosystem services, particularly water quality, are likely to deteriorate as a result. Although policies have been implemented to prevent new introductions globally (McGeoch *et al.*, 2010 see chapter 6), the increase in the numbers of non-native species shows no sign of saturation over time. Also, many non-native species are predicted to spread worldwide in the next decades, mainly because of climate change, accelerated economic exchanges among countries, construction of new transportation corridors and increased aquaculture (Seebens *et al.*, 2017). These projections seem to occur in all RCP scenarios but especially so under the RCP 4.5, 6.0 and 8.5.

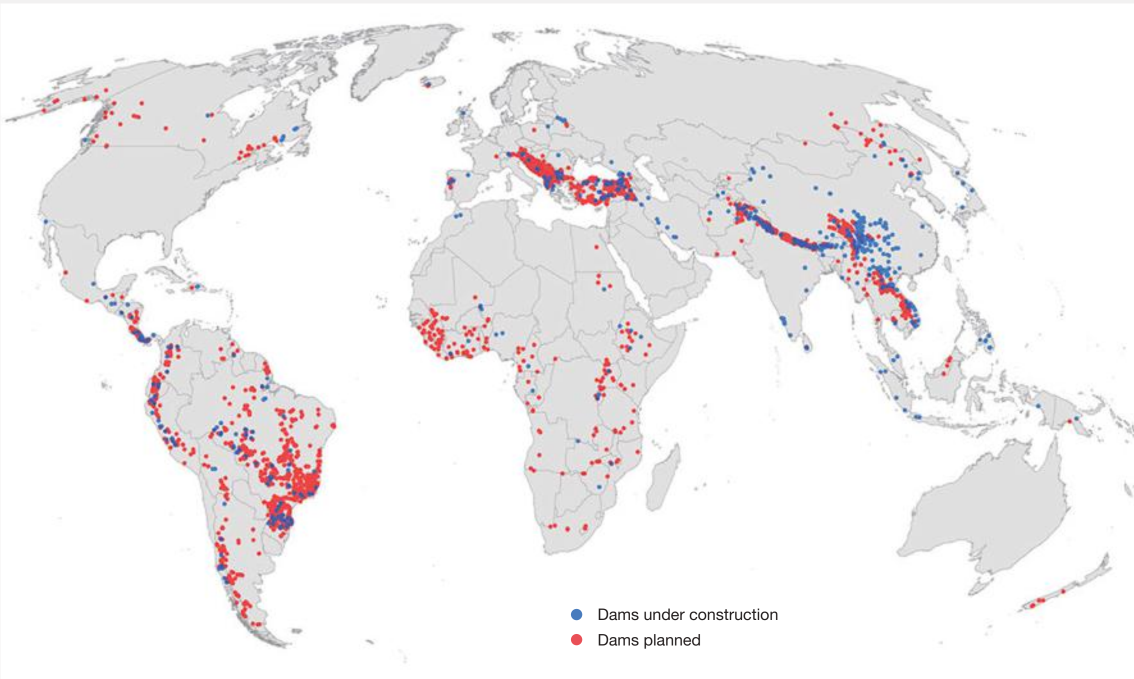


Figure 4 2 13 **Distribution of future hydropower dams, either under construction (blue dots 17%) or planned (red dots 83%).**

Source: Zarfl *et al.* (2015).

4.2.3.6 Future impacts of harvest on freshwater biodiversity and functioning

Irrespective of the exact type of scenario, given that human population density is continuously growing, increased harvesting is expected. Tropical ecosystems are of greatest concern. Intensive harvesting will deplete large-bodied fishes with consequent shifts toward harvests of smaller species and younger individuals with potential top-down effects on food web dynamics.

Current estimates of inland fisheries harvest are greatly underestimated (Deines *et al.*, 2017), but inland fisheries provide food for billions and livelihood for millions of people worldwide (FAO, 2016), and will continue to do so especially in developing countries. Low-income food-deficient countries account for ~80% of the total reported harvest from inland capture fisheries (Lynch *et al.*, 2016). Most global harvesting is concentrated in 16 countries, which have annual inland catches >200,000 tons and together represent 80% of the world total (FAO, 2016). Asian countries represent 63% of global total catches and African nations >13%. Harvests in African and Asian water bodies are already declining, probably because of environmental degradation and overexploitation (FAO, 2016). Given expected human population increases in Africa and Asia, increased harvesting is expected in both continents, whatever the RCP scenario. Because harvesting decreases population densities and large-bodied species, increased fishing pressure will lead to local extirpations of these species and will alter community structure and food web dynamics (Allan *et al.*, 2005; McIntyre *et al.*, 2016). These effects will be magnified by interactions with the other anthropogenic stressors listed above, including climate change. Because contributions of inland fisheries to economic security are inversely proportional to development level, rural economies in developing countries will be most affected.

4.2.3.7 Future impacts on peatlands

Peatlands are important flor global carbon cycling projections because they account for about one-third of the total carbon stored in soil organic matter (Page *et al.*, 2011) and also because many peatlands are an important source of methane (CH_4) (Kirschke *et al.*, 2013; Saunois *et al.*, 2016). Peatlands are threatened by future agriculture, forestry, peat extraction and dam construction activities (Minayeva *et al.*, 2017), which already over recent decades have begun transforming peatlands from greenhouse gas sinks to sources (Frolking *et al.*, 2011; Strack, 2008). For example, 15% of global peatlands have been drained worldwide and these drained peatlands are currently responsible for ~5% of all global anthropogenic CO_2 emissions (Strack, 2008).

While some regions appear to be improving peatland protection, others are increasing peatland destruction (Giam *et al.*, 2012; Hooijer *et al.*, 2010; Jauhiainen *et al.*, 2012; Koh *et al.*, 2011). Climate change is projected to possibly amplify shifts of peatlands from GHG sinks to sources, especially in regions where water tables are highly sensitive to local precipitation and where permafrost is melting (Dargie *et al.*, 2017; Turetsky *et al.*, 2015). A model intercomparison experiment showed that both peatland area and CH_4 emissions were less sensitive to potential future changes in precipitation than to increases in either atmospheric CO_2 or temperature (Melton *et al.*, 2013), but models disagree widely in both the magnitude and sign of potential climate effects on peatlands.

Where demands for water, food and energy put increasing pressure on the land resources, it is likely that peatland area will continue to decline (http://luh.umd.edu). Consequently, CO_2 emissions from peat decomposition and oxidation will expectedly persist well beyond the 21st century. Tropical regions are projected to be most affected under scenarios where much agriculture and bioenergy production relocate from high-income to low-income regions (Lawrence *et al.*, 2016). Considering the over proportional warming projected for subarctic and arctic ecosystems and the large amount of carbon stored in peatlands on permafrost soils, large climate warming feedbacks have been projected (Koven *et al.*, 2011; Page & Baird, 2016).

While plant and animal taxonomic diversity in peatland ecosystems is apparently low, highly specialized species predominate, with 5–25% of peatland plant species being endemic (Minayeva *et al.*, 2017). Many animal species occupy peatlands only at certain life stages or during particular seasons (but see Giam *et al.*, 2012 for some narrowly adapted fish species). Because of their unique flora, projected lost peatland area has implications for global biodiversity. In all scenarios, and without peatland conservation practices, climate change and other anthropogenic drivers are expected to disrupt peatland biodiversity to varying degrees, ranging from decreased population sizes to altered species composition and regional or global extinctions (Fraixedas *et al.*, 2017; Giam *et al.*, 2012; Hedwall *et al.*, 2017). For example, in Southeast Asia, if current rates of peatland conversions to agriculture continue through 2050, several fish species will become globally extinct (Giam *et al.*, 2012).

4.2.4 Terrestrial ecosystems

4.2.4.1 Future climate change and atmospheric CO_2 impacts on habitats, biodiversity, and ecosystem state and functioning

4.2.4.1.1 Climate change impacts on vegetation cover

Global vegetation and Earth system models all project substantial climate change driven shifts of natural vegetation cover over the next century (Davies-Barnard *et al.*, 2015; Gonzalez *et al.*, 2010; Ostberg *et al.*, 2013; Pereira *et al.*, 2010; Reu *et al.*, 2014; Sitch *et al.*, 2008; Wårlind *et al.*, 2014; Warszawski *et al.*, 2013). Area losses of natural vegetation are estimated to be 2-47% of terrestrial ecosystems for even relatively small temperature increases (<2°C above pre-industrial; Warren *et al.* (2011), and references therein). Other analyses confirm the risk of changes in vegetation cover (e.g., forest to non-forest or vice versa) for relatively small global temperature increases, especially in tundra, tropical forest and savanna regions but with changes within a given biome likely to occur in all regions (Gonzalez *et al.*, 2010; IPCC, 2018, Chapter 3.4.3; Ostberg *et al.*, 2013; Scholze *et al.*, 2006; Warszawski *et al.*, 2013). Biome shifts and associated impacts on ecosystem functioning increase notably in higher-warming scenarios (Ostberg *et al.*, 2013; Scholze *et al.*, 2006; Warren *et al.*, 2011; Warszawski *et al.*, 2013). Enhanced tree mortality from wildfires and increased drought and heatwaves can amplify vegetation responses to climate in models (Allen *et al.*, 2010; Lasslop *et al.*, 2016; Tietjen *et al.*, 2017).

4.2.4.1.2 Climate change impacts on species diversity

In principle, climatic changes could be favourable to some species in cases when a new climate can provide more resources for species growth, reproduction and distribution (Bellard *et al.*, 2012). However, even by the middle of the 21st century, or for relatively minor temperature changes, indices for animal and plant species richness have been projected to decline, and indices of species losses, enhanced (Alkemade *et al.*, 2013, 2009; Bellard *et al.*, 2012; Gonzalez *et al.*, 2010; IPCC, 2018, Chapter 3.4.3; Pereira *et al.*, 2010; Settele *et al.*, 2014; Warren *et al.*, 2011). Climate change has also been identified as a major driver of terrestrial species loss across all IPBES regional assessments (Bustamante *et al.*, 2018; Elbakidze *et al.*, 2018; Nyingi *et al.*, 2018; Wu *et al.*, 2018). A recent meta-analysis of studies reported that a global mean temperature increase of 2°C would threaten one in 20 species (for 5.2% of species, the distributional range falls below a minimum threshold), increasing to one in 12 and one in 6 species for 3°C and 4.3°C, respectively (Urban, 2015). Model projections across a range of scenarios show regionally highly variable extinction risks for terrestrial species on average between ca. 5-7% (Europe, Northern America) to ca. 25% (South America), ca. 9% in the tropics, and ca. 5% in temperate, polar and boreal environments, by 2100 (Maclean & Wilson, 2011; Urban, 2015). The projected extinction risk increases strongly with degree of global warming (Urban, 2015). Large uncertainties exist: for instance, extinction risks estimates when based on extrapolation of past observed trends have been found to be higher than the estimates based on model projections (Maclean & Wilson, 2011).

Climate change will impact biodiversity hotspots. Two contrasting future scenarios at the end of the 21st century have been estimated to negatively influence 25% of endemic species on average per hotspot, with largest effects in low latitudes, island locations and in Mediterranean type climates (Bellard *et al.*, 2014). Nearly all of the 143 investigated terrestrial regions in the Global 200 list of ecoregions that have been identified to support maintaining a broad diversity of Earth's ecosystems, will likely experience by the end of the 21st century moderate-to-pronounced climate change impacts, across a range of climate change scenarios (Li *et al.*, 2013).

Since the magnitude but also the velocity of climate change are chief determinants of whether (and which) terrestrial animal or plant species will be able to follow shifting habitats (Foden *et al.*, 2013; Gonzalez *et al.*, 2010; Keenan, 2015; Loarie *et al.*, 2009; Pecl *et al.*, 2017; Pereira *et al.*, 2010), the combination of abiotic and biotic characteristics that have not been observed in the past might be increasingly common in the future (Murcia *et al.*, 2014; Ordonez *et al.*, 2016; Radeloff *et al.*, 2015). Projected future changes in species ranges, species extinctions and community diversity therefore may be under– or overestimated by models that do not explicitly account for species interactions such that loss (or gain) of one species would trigger loss (or gain) for others (Bellard *et al.*, 2012; Schleuning *et al.*, 2016). As a consequence, new approaches to conservation are warranted that are designed to adapt to rapid changes in species composition and ensuing conservation challenges.

4.2.4.1.3 The combined impact of atmospheric CO_2 concentration and climate change on projected vegetation cover

Increasing atmospheric CO_2, the chief driver of climate change, also enhances relative competitiveness of plants of the C3 photosynthetic pathway by fostering carboxylation reactions in the leaf and allowing plants to operate at reduced stomatal conductance (Higgins & Scheiter, 2012; Pugh *et al.*, 2016b; Walker *et al.*, 2015). Whether or not enhanced photosynthesis or enhanced water use efficiency translates also into enhanced plant growth is not yet unequivocally established (Higgins & Scheiter, 2012; Pugh *et al.*, 2016b; Walker *et al.*, 2015). Globally, increased forest cover over the 21st century has been projected across a range of scenarios (Davies-Barnard *et al.*, 2015; Reu *et al.*, 2014; Sitch *et al.*, 2008; Wårlind *et al.*, 2014). Typically, forest cover increases in northern latitudes (Davies-Barnard *et al.*, 2015; Reu *et al.*, 2014; Sitch *et al.*, 2008; Wårlind *et al.*, 2014). A shift from grass- to increasingly woody-dominated vegetation (see Nyingi *et al.*, 2018) is simulated in semi-arid regions (Knorr *et al.*, 2016; Lehmann *et al.*, 2014; Lehsten *et al.*, 2009; Moncrieff *et al.*, 2014, 2016; Scheiter *et al.*, 2015). Impacts of enhanced CO_2 on canopy structure and combustible biomass alter fire regimes, with complex ecosystem feedbacks (Harris *et al.*, 2016; Jiang *et al.*, 2017; Kim *et al.*, 2017; Knorr *et al.*, 2016; Loudermilk *et al.*, 2013; Turco *et al.*, 2014; Wu *et al.*, 2015). Large-scale forest "die-back" emerges only in relatively few simulation experiments that examined future climate change and CO_2 impacts in tropical forest regions, especially the Amazon (Aragão *et al.*, 2014; Duran & Gianoli, 2013; Gumpenberger *et al.*, 2010; Malhi *et al.*, 2009, 2008; Nobre *et al.*, 2016; Poulter *et al.*, 2010; Rammig *et al.*, 2010; Schnitzer & Bongers, 2011). These model outcomes are supported by analyses that attributed the observed greening trends in many regions and (C3) shrub encroachment in C4-dominated grasslands chiefly to CO_2 fertilisation effects (Donohue *et al.*, 2013; Schimel *et al.*, 2015; Stevens *et al.*, 2016; Zhu *et al.*, 2016). Increases in woody vegetation in grass-dominated regions are expected to negatively impact grassland-related biodiversity (Barbosa da Silva *et al.*, 2016) but intermediate levels of woody cover might in some cases be beneficial for ecosystem functioning such as carbon storage, reduction of soil erosion and overall plant and animal species diversity (Barbosa da Silva *et al.*, 2016; Eldridge & Soliveres, 2014; Soliveres *et al.*, 2014).

4.2.4.1.4 Projected changes in ecosystem state and function

The uptake of CO_2 in land ecosystems is large, with 20-25% of anthropogenic emissions being removed from the atmosphere each year (Le Quéré *et al.*, 2018; see also Chapter 2.2, section 2.2.5.2.2). The future persistence of this land carbon "sink" is one of the largest uncertainties in climate research. It is important to address because of the potentially large warming feedback associated with a loss of the land sink (Arneth *et al.*, 2010; Ciais *et al.*, 2013). The direction (but not the magnitude) of the change in global terrestrial carbon uptake and pool sizes in response to climate change alone vs. increased CO_2 concentration alone is modelled relatively robustly (Ciais *et al.*, 2013; Hajima *et al.*, 2014; Nishina *et al.*, 2015; Sitch *et al.*, 2008; Walker *et al.*, 2015; Zaehle, 2013). However, when effects of climate change and CO_2 concentration are considered jointly, the rate and even the sign of change in simulated trajectories of future ecosystem C pools and related fluxes are highly inconsistent between ecosystem carbon cycle models (Ciais *et al.*, 2013; Eglin *et al.*, 2010; Friend *et al.*, 2014; Nishina *et al.*, 2015; Piao *et al.*, 2013; Sitch *et al.*, 2008). The latest IPCC report places low confidence on how stocks and fluxes will evolve over the coming decades (Ciais *et al.*, 2013).

Evapotranspiration (ET) from ecosystems is greatly altered by changes in leaf area, functional vegetation type, precipitation and atmospheric dryness, and the response of stomatal conductance to CO_2. Whether or not global or regional run-off (which affects availability of water for irrigation but also floods) will increase in the future due to enhanced water cycles in a warmer climate, or possibly reduced ET in a higher CO_2 world is unresolved. Similar to projections of ecosystem productivity and carbon balance, uncertainty arises from both variability in climate change projections and from process descriptions in impact models (Döll & Schmied, 2012; Piao *et al.*, 2007; Zhang *et al.*, 2014).

Overall, climate change, and change in atmospheric CO_2 levels will strongly impact productivity and other important ecosystem processes, vegetation cover, and habitat structure over the next decades, with the relative importance of these drivers differing between biomes/regions (see **Figure 4.2.2** and Table A4.2.1).

4.2.4.2 Future land-use and land-cover change impacts on habitats, biodiversity, and ecosystem state and functioning

Nearly 40% of the land surface today is used as croplands or pastures, and humans have transformed the vegetation structure and species composition in an area far greater still (Ellis, 2013; Ellis *et al.*, 2012; see also Chapters 2.1 and 2.2). Local within-sample richness, rarefaction-based species richness, and total abundance have all been shown to be generally lower in areas under different types and intensity of land use, compared with natural vegetation (Alkemade *et al.*, 2009; Newbold *et al.*, 2015; Wilting *et al.*, 2017; Chapter 2.2.). In some cases, species richness, at least for plants, can also increase under land use, such as documented in local management systems for agriculture and agroforestry, forests, meadows and grasslands found around the world (Ellis *et al.*, 2012; Gerstner *et al.*, 2014; see also Chapter 2.2). Both, changes in land cover and land use, are known to impact biodiversity and ecosystem functioning globally (Foley *et al.*, 2011; Kleijn *et al.*, 2009; Pywell *et al.*, 2012). But across large scales, studies typically assess impacts of land cover changes, rather than intensification of management at a given area of land which limits our ability to understand the combined effect of land-use and land-cover change (de Chazal & Rounsevell, 2009; Titeux *et al.*, 2017).

Humid or mesic savannas and woodlands seem particularly vulnerable to future conversion of natural vegetation into cropland or pasture, because of their climate suitability for agriculture. Land-use changes have been very pronounced in recent decade; for example, in the Cerrado or Chaco regions of South America, but also in African savannas (Aleman *et al.*, 2017, 2016; Cavender-Bares *et al.*, 2018; Nyingi *et al.*, 2018; Searchinger *et al.*, 2015; see also Chapter 2.1).

Land conversion pressure is large both in scenarios that explore high population growth and lack of consideration for sustainable development (e.g., lack of conservation efforts, little consumption change), as well as in strong mitigation scenarios that require land for bioenergy or afforestation (Popp *et al.*, 2017; see also section 4.2.4.3). Due to large land area requirements, maintaining or enhancing biodiversity and ecosystem functionality (such as productivity and changes in carbon pools or changes in water cycling) would be challenging under such socio-economic projections (Krause *et al.*, 2017, 2018; Popp *et al.*, 2017; Ryan *et al.*, 2016; Searchinger *et al.*, 2015).

Projections of future biodiversity at the global level have until recently been biased towards climate change related questions (Titeux *et al.*, 2016, 2017). Anthropogenic land-cover changes have been relatively well studied at the regional and local levels, particularly but not only in tropical forests regions, but are only slowly beginning to be considered in global scenario projections. Declining forest cover and/or reduced average local species richness, for 2050 and until the end of the 21st century have been found under "economic optimism" scenarios, such as the SSP5/RCP8.5 which projects large greenhouse gas emissions and climate change effects along with substantial expansion of cropland or pastures (Davies-Barnard *et al.*, 2015; Newbold *et al.*, 2015), or under scenarios that assume the absence of a REDD scheme (Strassburg *et al.*, 2012). Interactions of future climate change with land-cover change were shown to enhance risk of biodiversity loss by up to 43% for birds and 24% for mammals, compared to land-cover change impacts only (Mantyka-Pringle *et al.*, 2015). By 2050 in a business-as-usual scenario, climate and land-cover change were shown to lead to a decline in mean terrestrial carnivore and ungulate population abundance by 18-35%, and to an increase in extinction risk for 8-23% of species (Visconti *et al.*, 2016). Negative impacts are also projected to arise from land-cover and land-use changes on a range of threatened carnivores in an OECD Environment Outlook scenario (Di Minin *et al.*, 2016). Taken together these studies demonstrate that across a range of scenarios, expansion of managed land is projected to pose additional pressure on biodiversity. The relative impacts of climate change versus land-use change on biodiversity, however, are context-specific and vary between scenarios and regions, and depend on the biodiversity indicator or facet of biodiversity under scrutiny, as emphasised by the four regional IPBES assessments (e.g., Bustamante *et al.*, 2018; Elbakidze *et al.*, 2018; Nyingi *et al.*, 2018; Wu *et al.*, 2018) and also by very recent results emerging from the BES-SIM study (Kim *et al.*, 2018; **Box 4.2.5**; see also section 4.1).

Future anthropogenic land-cover change will also impact protected areas and the associated protected species range (see section 4.6). Even when implemented efficiently, the percentage area protected would have to increase to capture a similar rage of terrestrial vertebrate species range in simulations that include projections of land cover change over the next two decades, compared with land-cover change remaining at present-day levels (Montesino Pouzols *et al.*, 2014).

Box 4 2 5 Biodiversity and nature's contributions to people in the Shared Socio-economic Pathway scenarios: a model inter-comparison.

Background. In 2016, IPBES created a task force to support the scientific community in developing scenarios and models to provide IPBES and other stakeholders with greatly improved capacity to assess the future impacts of global environmental change on biodiversity and nature's contributions to people (IPBES, 2016b; Rosa *et al.*, 2017). This work focuses on two complementary tasks. The first task is to work closely with the climate change community to analyze and extend the 'Shared Socio-economic Pathways (SSP)' scenarios and associated climate change projections that have been developed in support of the IPCC (Rosa *et al.*, 2017). The results presented below are the first outcomes from this task referred to as BES-SIM (Kim *et al.*, 2018). The second task is to develop a set of multi-scale, participatory based scenarios that explicitly account for nature conservation objectives. This task is ongoing, and the outcomes will only become available for future assessments.

The results presented below are from the first-ever comparison of multiple models of terrestrial biodiversity, ecosystem functioning and ecosystem services at the global scale using a common set of inputs for climate and land-use change drivers (Kim *et al.*, 2018), addressing shortcomings in previous comparative attempts that have been hampered by the lack of a common methodology (Bellard *et al.*, 2012; Pereira *et al.*, 2010; Settele *et al.*, 2014; Urban, 2015; Warren *et al.*, 2011). Using a total of 14 participating models, ten different indicators of biodiversity were simulated and six models contributed simulations of ecosystem function and ecosystem services (Kim *et al.*, 2018).

All models of biodiversity, ecosystem function and ecosystem services used harmonized land-use inputs from three SSP scenarios in combination with three scenarios of greenhouse gas emissions (RCP) and corresponding projected climate change (Kim *et al.*, 2018):

- SSP1 x RCP2.6 – is a 'global sustainability' scenario archetype (SSP1) combined with low GHG emissions (RCP2.6),
- SSP3 x RCP6.0 – is a 'regional competition' scenario archetype (SSP3) combined with high GHG emissions (RCP6.0), and
- SSP5 x RCP8.5 – is an 'economic optimism' scenario (SSP5) combined with very high GHG emissions (RCP8.5).

Climate and land-use change projections from these three sets of scenarios (see section 4.1.4, and Appendix A4.2.3) were evaluated for their consequences for biodiversity, ecosystem functions and ecosystem services. In addition, some of the participating models evaluated the impacts of climate change and land-use change individually, as well as in combination. Outputs from ecosystem functioning and ecosystem services models have been grouped into categories of nature's contributions to people as defined in Diaz *et al.* (2018).

Biodiversity and regulating nature's contributions to people are projected to decline while material contributions to people increase by 2050. The global average of projected impacts on biodiversity and on nature's contributions to people are shown in **Figure 4.2.14**. The combined impacts of climate and land-use change on biodiversity include large declines in local species richness, increases in regional to global scale species extinction and declines in biodiversity intactness. Several important regulating ecosystem services, such as coastal protection, soil erosion protection and crop pollination, are projected to decline in the 'regional competition (SSP3xRCP6.0)' and 'economic optimism (SSP5xRCP8.5)' scenarios.

In contrast, food, feed, timber and bioenergy production services are projected to substantially increase in these scenarios. This pattern of trade-offs between declining biodiversity and regulating contributions on one hand vs. increasing material contributions on the other hand are coherent with recent patterns (Carpenter *et al.*, 2009; see Chapters 2 and 3) and with a wide range of studies of biodiversity and ecosystem services evaluated in this chapter (sections 4.3 and 4.5).

Not all of the metrics follow this general pattern. One important example is ecosystem carbon storage at the global scale, which is an indicator of the capacity of ecosystems to contribute to climate change mitigation. Global scale ecosystem carbon storage is projected to be stable or increase in nearly all scenarios and in all ecosystem models by 2050 (see Table A4.2.2 in Appendix A4.2.3). This occurs in part because rising atmospheric CO_2 concentrations and rising temperatures (up to certain point) stimulate modeled plant productivity and ecosystem carbon storage, as well as the result of land-use change in the scenarios.

***There are large regional differences in the patterns of biodiversity loss and changes in nature's contributions to people with the largest projected impacts in the global south* (Figure 4.2.15)**. The projected effects of land use and climate change on three metrics of biodiversity, material nature's contributions to people and regulating nature's contributions to people for the IPBES subregions are shown in Figure A4.2.1 in Appendix A4.2.3. The general patterns at the global level – i.e., declines in biodiversity and regulation contributions vs. increases in material contributions – are evident in nearly all subregions. Biodiversity in South America, Africa and Asia (with the exception of northeast Asia) is much more heavily impacted than in other regions, especially in the regional competition and economic optimism scenarios. Ecosystem carbon storage shows particularly contrasted regional responses, with very large declines projected for Africa. These regional differences occur in part because scenarios foresee the largest land-use conversions to crops or bioenergy in these regions (see section 4.1.5 and Appendix A4.1.2). Other regions such as North America and Europe are foreseen to have low conversion to crops and continued trends of afforestation which minimizes declines in biodiversity, or even increases in some regional biodiversity metrics. Regional differences in climate change impacts also play a major, and sometimes dominant role in regional contrasts.

The magnitude of impacts and the differences between regions are much greater in scenarios of regional competition and economic optimism than in a scenario of global sustainability. Biodiversity loss at the global scale is much lower in the global sustainability scenario (SSP1xRCP2.6) than in the regional competition and economic optimism scenarios and even improves for the biodiversity intactness metric. Several regulating services, such as crop pollination and soil protection, increase at the global scale in the global sustainability scenario instead of declining as in the other two scenarios, and in general, the impacts of land use and climate change are much greater in the regional competition and economic optimism scenarios **(Figure 4.2.14)**. In contrast, the global sustainability scenario results in substantially lower projected food, feed and timber production, but it is important to note that this arises primarily from lower demand rather than insufficient supply of food and timber to people. The regional competition and economic optimism scenarios also are projected to generate much greater regional contrasts in biodiversity and nature's contributions than the global sustainability scenario **(Figure 4.2.15)**. But caution should be exercised when generalizing from these three scenarios because there is substantial variation in land use and other drivers within each of the main Shared Socio-economic Pathway classes (Popp *et al.*, 2017).

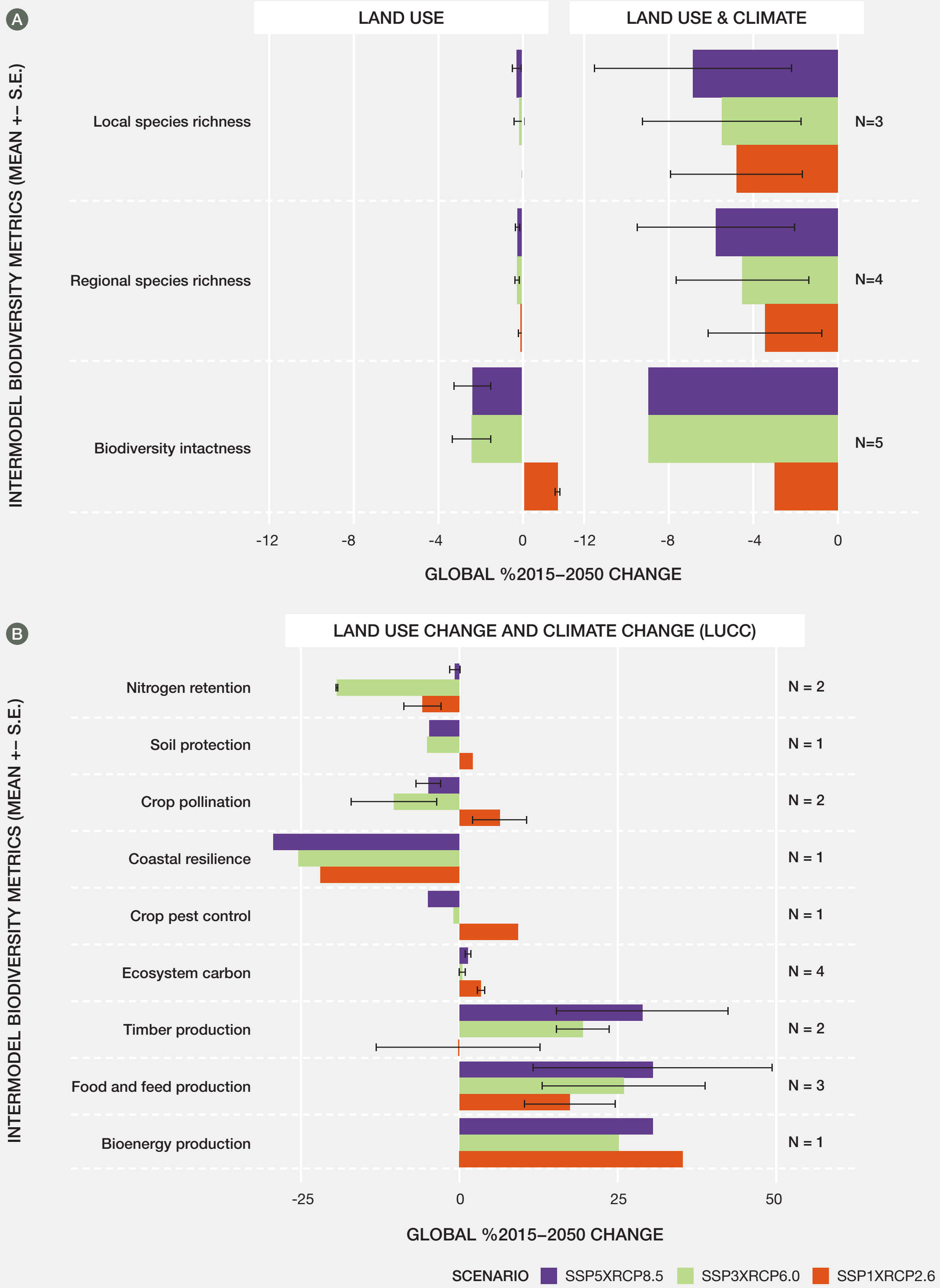


Figure 4 2 14 **Global means of projected percent changes in biodiversity A and nature's contributions to people B between 2015 and 2050.**

Biodiversity metrics include changes in local species richness (= number of species in a small area), regional species richness (number of species at regional or global scales, the opposite of which is regional or global extinction), and biodiversity intactness (i.e., abundance of plant and animal communities in disturbed compared to undisturbed natural ecosystems). Values are averages across models, which number is indicated by N. Standard errors across models are indicated by whiskers when more than one model projection was available. The three SSPxRCP scenarios are defined in the box text.