CBD

Convention on
Biological Diversity

Distr.
GENERAL

CBD/SBSTTA/21/INF/2
21 November 2017

ENGLISH ONLY

SUBSIDIARY BODY ON SCIENTIFIC,
TECHNICAL AND TECHNOLOGICAL ADVICE
Twenty-first meeting
Montreal, Canada, 11-14 December 2017
Item 3 of the provisional agenda[*]

REVIEW OF FUTURE PROJECTIONS OF BIODIVERSITY AND ECOSYSTEM SERVICES

Note by the Executive Secretary

1. The Executive Secretary is circulating herewith, for the information of participants in the twenty-first meeting of the Subsidiary Body on Scientific, Technical and Technological Advice, a review of future projections of biodiversity and ecosystem services. The note has been prepared by the UN Environment World Conservation Monitoring Centre in consultation with the Secretariat of the Convention on Biological Diversity,[1] with the generous financial support from the United Kingdom of Great Britain and Northern Ireland.

2. The present note is relevant to the deliberations of the Subsidiary Body on Scientific, Technical and Technological Advice, in particular as it provides additional information relevant to CBD/SBSTTA/21/2, section III C, which focuses on ongoing work related to the development of scenarios on biodiversity, land use, climate change and sustainable development.

3. The report is presented in the form and language in which it was received by the Secretariat.

---

[*] CBD/SBSTTA/21/1.

[1] Authors: Tittensor, D. P., Baquero, A., Harfoot, M. and Hill, S. Contributors: Burgess, N., Ferrier, S., McOwen, C., Scott, E., Shin, Y.-J.

REVIEW OF FUTURE PROJECTIONS OF BIODIVERSITY AND ECOSYSTEM SERVICES

I. INTRODUCTION AND SCOPE

1. The 2050 Vision of the Convention on Biological Diversity's (CBD) Strategic Plan for Biodiversity 2011-2020 is that '*biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet, and delivering benefits essential for all people.*' To achieve this 2050 Vision it is necessary to assess where we stand at present, but also to evaluate where we are heading, and how alternative policies and socio-economic developments may affect this trajectory.

2. To determine the trajectories of biodiversity and ecosystem services, we can use *projections* of *trends*, often generated by *models* and frequently forced by specific *scenarios* of socio-economic development and climate (all italicised words defined below).

3. The purpose of this document is to review recent information from the scientific literature on the status, trends, and projections of global biodiversity and ecosystem services, and to describe how this can be used to inform how the 2050 Vision might be achieved. Our starting point is the CBD's 2014 Global Biodiversity Outlook 4 (GBO4) (Secretariat of the Convention on Biological Diversity, 2014). We then build upon this through identifying assessments and projections of the state of biodiversity in the scientific literature since that time. We compare projections for biodiversity and ecosystem services under 'business as usual' scenarios to projections under alternative scenarios, identify gaps and uncertainties, and finish by examining the relevance of recent projections and scenarios for achieving the 2050 Vision.

Terminology

4. Here we consider 'biodiversity' in a broad sense (using the CBD's definition of "biological diversity" as "*the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems"*). We consider 'ecosystem services' as both goods and services that represent the "*direct and indirect contributions of ecosystems to human wellbeing"*[2].

5. 'Scenarios', in the sense used herein, are depictions or storylines of plausible or possible societal futures that can then be used to explore trajectories of biodiversity and ecosystem services, along with a range of policy or management options, into the future. Specifically, following the definition of the IPBES Methodological Assessment on Scenarios and Models of Biodiversity and Ecosystem Services, scenarios are "*plausible representations of possible futures for one or more components of a system, or […] alternative policy or management options intended to alter the future state of these components.*" (IPBES, 2016).

6. 'Business-as-usual' (BAU) is used to indicate a scenario in which societal variables, policies, economics, and other dynamics continue to follow their current pathways, without radical changes or shifts at global scales. These scenarios can represent baselines for biodiversity assuming the continuation of current socioeconomic paradigms, and can help to indicate biodiversity trajectories against which alternate scenarios of societal development may be compared.[3]

---

[2] The definition used by The Economics of Ecosystems and Biodiversity (www.teebweb.org)

[3] Note that, in practice, there may be a range of BAU scenarios, depending on assumptions about the continuation of current trends. For example, some BAU scenarios include GHG emissions that, in the light of the actions taken and commitments made in the context of Paris Agreement may now be considered as or closer to 'high emissions' (see paragraph 59).

7. ‘Trend’ is used in the sense of the general direction in which ecosystems or biodiversity are heading, and ‘projection’ is taken to mean specific (largely quantitative) trajectories that are generally produced by models, which themselves are often forced using specific scenarios.

8. ‘Models’ as defined in IPBES (2016) are ‘*qualitative or quantitative representations of key components of a system and of relationships between these components’*.

The use of scenarios in informing projections

9. Scenarios can be used to ‘force’ statistical or mathematical models of biodiversity or ecosystems, and hence to explore a range of possible or plausible biodiversity futures under various assumptions of political, technological, and socio-economic development. They are an important step in clarifying the socio-economic assumptions that underlie projections, and provide the foundation or storyline for models to interpret into (generally) quantitative outcomes, often for a specific date in the future (e.g. 2030, 2050, or 2100). Scenarios can be global, regional, national, sub-national, or local. They can cover specific ecosystems or habitats, or specific sectors (e.g. agriculture)[4].

10. The IPBES methodological assessment describes four types of scenarios: ‘exploratory’ (descriptions of how the future might unfold, based on potential trajectories of drivers); ‘target-seeking’ (a future end-point or target is specified, and the scenario describes a societal trajectory to reach that end point); ‘policy-screening’ (designed to explore various policy alternatives or options); and ‘retrospective policy evaluation’ (designed to explore the gap between a policy implemented in the past and pathways that would have achieved a particular target) (IPBES, 2016). Exploratory scenarios are associated with ‘agenda setting’, often based on storylines – i.e. identification of high-level problems and providing a means to explore and discuss issues. Target-seeking and policy-screening scenarios, in the IPBES context, are ‘intervention’ scenarios, in that they specifically evaluate management or policy alternatives, and can aid with policy design and implementation. Retrospective policy evaluation scenarios provide an approach to review and evaluate an historically implemented policy in comparison to hypothetical alternatives (IPBES, 2016).

11. In GBO-4, an assessment of the prospects for meeting the 2050 Vision was conducted through comparing trends from a BAU scenario to three alternative ‘pathways’ which required major or transformational societal change (Secretariat of the Convention on Biological Diversity, 2014). These alternatives were extensions of the “Roads from Rio+20” scenarios: a ‘global technology’ pathway, with strong international coordination and a focus on technological solutions, a ‘decentralized solutions’ pathway, with regional prioritization driving adaptive management practices, and a ‘lifestyle change’ pathway focussing on a reduction of consumption and behavioural change, such as energy and material use, and food wastage.

12. Two important sets of scenarios that are commonly used for biodiversity projections derive from the Intergovernmental Panel on Climate Change (IPCC). The first is the Representative Concentration Pathways (RCPs) (van Vuuren et al., 2011). The RCPs assume particular greenhouse gas (GHG) concentrations and levels of radiative forcing over time. These can then be used to derive future changes in variables such as global air temperature, emissions, and land use change consistent with each RCP. There are four RCPs, each of which could arise from various combinations of socio-economic trajectories; we describe four pathways here (van Vuuren et al., 2011). RCP8.5 (hereafter referred to as ‘*high emissions*’) has a continual rise in GHG concentration and radiative forcing, and results in a temperature of 4°C above pre-industrial and

---

[4] For more on scenarios, see CBD/SBSTTA/21/2 ‘Scenarios for the 2050 Vision for biodiversity’.

an increase in agricultural area by 2100. RCP6.0 (hereafter ‘*medium emissions*’) and RCP4.5 (hereafter ‘*medium-low emissions*’) are intermediate scenarios with somewhat lower GHG concentrations, temperatures of 2.5°C and 1.75°C above pre-industrial, and low and very low agricultural areas by 2100. The RCP2.6 (hereafter ‘*low emissions*’) scenario has a stabilization and then a decline in GHG concentration, a 1°C temperature increase above pre-industrial, and a large increase in biofuel plantations by 2100. Of relevance to the 2050 Vision, RCP2.6 represents around a 1°C mean increase in global surface temperature (relative to 1986-2005) by mid-century, RCP4.5 and RCP6.0 a 1.3°C and 1.4°C mean increase, and RCP8.5 a 2°C mean increase.

13. The second set of scenarios is the Shared Socioeconomic Pathways (SSPs) (O’Neill et al., 2013). The SSPs, rather than focus on specific radiative forcings without necessarily prescribing the pathways that lead to these outcomes, instead describe particular combinations of socio-economic development, population growth, and governance, which then affect trajectories of global change into the future. There are 5 SSPs: SSP1 (‘sustainability’), SSP2 (‘middle of the road’), SSP3 (‘regional rivalry’), SSP4 (‘inequality’), and SSP5 (fossil-fuelled development). See CBD/SBSTTA/21/INF/3 for further details on the SSPs.

II. RECENT ASSESSMENTS OF STATUS AND PROJECTIONS OF FUTURE TRENDS IN GLOBAL BIODIVERSITY AND ECOSYSTEM SERVICES

14. This section reviews how global projections, scenarios, and models of ecosystems provide information on the trajectory of change in biodiversity and ecosystem services over the coming century – and specifically how they are relevant to the 2050 Vision. The Global Biodiversity Outlook 4 report (Secretariat of the Convention on Biological Diversity, 2014) represents one of the more recent authoritative assessments of biodiversity status and trends, and is used as a starting point for discussion of more recent assessments in the scientific literature.

IIA. Terrestrial biodiversity status and trends

IIA.1. Current state of biodiversity and ecosystem services

15. The state of terrestrial biodiversity as described in GBO-4 can be briefly summarized as follows: the loss of forest habitats in some regions (e.g. the Brazilian Amazon) had slowed, though deforestation in many tropical regions is still increasing. However, there had been an increase in certified sustainable forestry. Habitats of all types continue to be fragmented and degraded. Pollutants (such as pesticides, chemicals, and plastics) were increasing. The rate of species invasions was increasing, despite steps to control and eradicate invasives. Terrestrial ecosystems especially vulnerable to climate change, such as cloud forest, had insufficient information available to be able to fully assess impacts. Protected areas were covering an increasing fraction of the land, though networks remain unrepresentative and some critical sites for biodiversity are poorly conserved. The mean extinction risk was increasing for amphibians, birds, and mammals. In all, it appeared unlikely that ecosystems could be kept within safe ecological limits at current patterns of consumption (Secretariat of the Convention on Biological Diversity, 2014).

16. Subsequent to GBO-4, considerable material has appeared in the scientific literature detailing the state of terrestrial biodiversity. Overall, the picture remains consistent with the findings of GBO-4 at the global level. Spatial patterns in changes of species richness (number of species in a particular area) are scale dependent. Globally, richness may be declining as human-induced extinctions occur, although this is hard to prove conclusively. Biodiversity at regional scales may show net increases due to species introductions. At local scales, land use change and other conversion of ecosystems causes declines in local diversity (e.g. Newbold et al. 2015), but in the absence of such impacts it appears that there is large variation but no mean trend (e.g. Velland et

al. 2017). The redistribution of species due to climate change is accelerating, with consequences for ecosystem services that are based upon existing biodiversity. There is evidence of changes in community composition, and species abundances show an overall mean decline, though the magnitude varies between taxa and studies. Protected area coverage continues to increase[5], though regions remain where coverage is low and threats high (Watson et al. 2016). Extinction rates are estimated to be far above background levels, and measures of extinction risk, including for taxa important for ecosystem services such as pollinators, suggest a general increase in risk. There remains limited information on global-scale changes in genetic diversity and some ecosystem services and threatened habitats.

17. *Species richness:* A global quantification of local (i.e. at individual sites) terrestrial biodiversity responses to land use and related changes demonstrated that, on average, samples had declined in species richness by 8.1%[6] by the year 2000 due to such impacts (Newbold et al., 2015). For the most-impacted sites, this value rose to 40.3%[7,8] (see Fig. 1). Vellend et al. (2013) and Dornelas et al. (2014) also demonstrated a wide range of changes in species abundance at local level, with an average change that was close to zero, for plants and multiple taxa respectively. However, Dornelas et al. did find that community species composition was systematically changing over time, potentially due to environmental change or biotic homogenization. These differences between studies may be due to the fact that Newbold et al. (2015) focussed on a range of sites from relatively natural to those that have undergone significant disturbance and land use conversion – i.e. compare reasonably ‘pristine’ directly to substantially impacted – whereas Dornelas et al. (2014) and Velland et al. (2013) looked along time-series from multiple locations which were not necessarily undergoing such disturbance patterns. Thus, conversion of natural ecosystems to croplands or urban environments appears to cause a local loss of biodiversity, but without these impacts there may be variation but no mean trend (Velland et al. 2017).

18. Biodiversity is also important for maintaining productive ecosystems, and its loss results in impacts on ecosystem services that human beings rely upon (Cardinale et al 2012; Duffy et al. 2017).

19. There is considerable evidence that suggests that species are being redistributed due to climate change (Pecl et al., 2017). The consequences of species redistributions include major changes in food supply (e.g. targeted species in fisheries), economic goods and services (such as changes in forest land suitability), biological pest control, pathogens and disease transmission, cultural and traditional knowledge systems, and climate feedback and carbon sequestration (Pecl et al., 2017).

---

[5] www.protectedplanet.net

[6] The 8.1% value refers to a ‘rarefaction-based richness’ measure, which standardizes for variation in the number of individuals within each sample among sites. An alternative measure, ‘within-sample richness’, the number of species in a standardized sampling unit at a given site (with sample sizes potentially varying between sites), gives an estimate of decline in species richness of 13.6%.

[7] 76.5% for within-sample richness.

[8] Note that Newbold et al. (2016) also found that within-sample richness had declined below a precautionary value (90% of undisturbed – see Steffen et al. 2015) on around 62% of the world’s surface, or 48% if novel species are assumed to contribute equivalent ecological function. See also footnote 6.

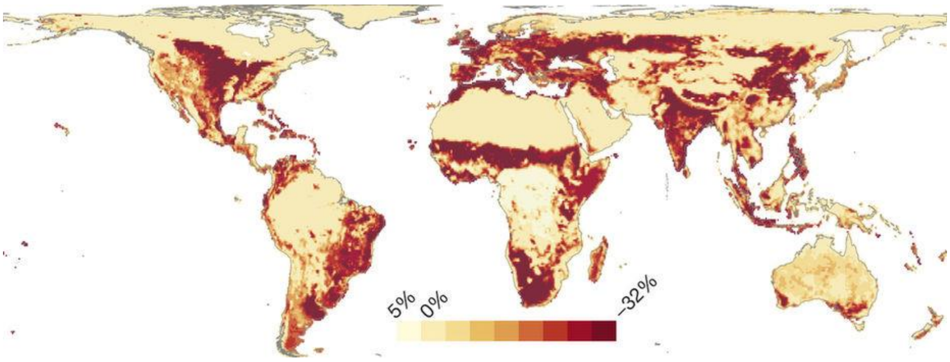

Figure 1: Net change in terrestrial local richness due to land use and related pressures by the year 2000. From Newbold *et al.* (2015)

20. *Species abundances:* Global trends in species abundances suggest that on average there have been declines, although the rates vary among studies and taxa. The Living Planet Index (LPI) is a measure of biodiversity that integrates population data for a variety of vertebrate species and calculates an average (geometric mean) temporal change in abundance[9] (WWF, 2016). The LPI suggested a strong population decline for vertebrate species, with the index showing a decline of 58% between 1970 and 2012 for all vertebrates considered, and 38% for terrestrial vertebrate populations. Just over half of species showed an increasing or stable trend in abundance (except for amphibians), but the magnitude of declines for those that were decreasing exceeded the magnitude for those increasing, resulting in a net decline in the LPI. Newbold et al. (2015) suggest a mean abundance decline in local samples of 10.7% relative to the absence of human effects. Newbold et al. (2016) examined global reductions in local biodiversity, using mean abundances for a range of species relative to undisturbed habitat, and suggested that for around 58% of the world's land surface, the mean abundance has been reduced below 90% (a 'precautionary' level proposed by Steffen et al. 2015) due to land use pressures[10].

21. Although not a global study, (Hallmann et al. 2017) recently analysed biomass trends in insects - a taxon generally under-represented in studies - within protected areas in Germany. They found a decline of more than 75% in flying insect biomass, with potentially serious consequences for ecosystem functioning, as insects are important as pollinators, detritivores, in nutrient cycling, and for other ecological processes. Overall, the recent literature suggests that for many, but not all, species there has been a decline in abundance.

22. There is a link between species abundance and ecosystem services, with abundance particularly important for pest regulation, pollination and recreation (Harrison et al. 2014), and hence any declines will impact the provision of such goods and services to people.

23. *Extinction rates:* Extinction rates remain hard to quantify. The most recent Red List Index (IUCN, 2017) estimated that 25% of evaluated species were threatened with extinction in 2017, while De Vos et al. (2015) estimated extinction rates to be around 1,000 times higher than natural

---

[9] Note that the LPI is the *geometric mean* of the change in abundance, so this *does not* represent the arithmetic mean change in abundance – i.e. it does not necessarily imply that the average species has declined by 58% in abundance; it reflects both evenness and abundance. Furthermore, some populations within the index are increasing rather than decreasing, with a range of different outcomes between species and regions.

[10] Note that this estimate assumes that novel species do not contribute to ecosystem function. Assuming that novel species contribute equivalently to original species, this value drops to around 48%. If novel species actually impair ecosystem function, the original estimate would be too optimistic. The authors suggest that this highlights the need for more research into how novel species affect ecosystem function.

background rates. Over 927 endemic species of birds, mammals and amphibians (28% of the total number of endemics for the three taxa) have been projected to go extinct due to current patterns of global land use (Chaudhary & Brooks *in press*).

24. *Genetic diversity:* Genetic diversity patterns at a global scale are only recently beginning to be mapped (Miraldo et al., 2016), so there is little or no relevant information on large-scale changes to date.

25. *Ecosystem services:* As indicated above, changes in species richness, abundance, and distribution will impact ecosystem functions and services (Cardinale et al. 2012; Duffy et al. 2017; Pecl et al. 2017). An assessment of trends in pollinating birds and mammals suggested that at a global scale, the Red List Index status of such species indicateed an overall move towards greater extinction risk (Regan et al., 2015).

IIA.2 Biodiversity trends under business as usual scenarios

26. The business-as-usual scenario in GBO-4 indicated large-scale negative and unsustainable impacts on terrestrial biodiversity and ecosystem services. Climate change was projected to become a major driver of ecosystem and biodiversity impacts, with species impacted by a range of factors including global temperature increases, altered patterns of precipitation, and rising sea-levels. The movement of species to stay in favourable climates (over 10km/year in some regions) would impact ecosystem services and reduce the effectiveness of protected areas, as well as increase the risks of species extinction (Leadley et al., 2014). Indices of local abundance and local species richness were projected to decline under BAU scenarios of land use and climate change. This was in part due to a substantially increased demand for fertile land for both agriculture and bioenergy, leading to insufficient room for, and putting pressure on, natural terrestrial habitats. The combination of anthropogenic drivers could push some regional social-ecological systems beyond tipping points and transition them to a new phase in which biodiversity and ecosystem services would become severely impacted. Additional serious ‘regime shifts’ were projected to be possible, if still speculative (Leadley et al., 2014).

27. Post-GBO4 studies that have examined a high-emissions[11] scenario suggest a continuing decline in biodiversity and ecosystem services, and therefore a corresponding inability to meet the 2050 Vision. Projections examined changes in species richness, abundance, or extinction risk, while other facets of biodiversity remained less explored. Further details are provided in the paragraph below.

28. Extrapolations of the LPI to 2020 under BAU suggested a continued decline in the index value to 67%[12] compared to the 1970 baseline (WWF 2016). Further out to 2050, Visconti et al. (2016) used a BAU[13] climate change and land use scenario, and found an 18-35%[14] decline in geometric mean population abundance (akin to the LPI), and an increase in species extinction risk for 8-23%[15] of species.

29. Further into the future, Newbold et al. (2015) projected future biodiversity impacts under land use changes associated with the RCP Scenarios (see paragraph 12 above. Note however, that the projections did not take into account the impacts of climate change). Under a scenario with high land use change (rapid increase in cropland area under the high-emissions scenario), local (within-

---

[11] RCP8.5

[12] Geometric mean of change in abundance

[13] IPCC SRES A1B; somewhere between RCP6.0 and RCP8.5 in terms of CO_2 concentration.

[14] Depending on species ability to adapt to climate change and disperse.

[15] Depending on species ability to adapt to climate change and disperse.

sample) richness was projected to fall an additional 3.4% by 2100, with the effects concentrated in biodiverse but economically disadvantaged countries. (Newbold et al., 2015).

30. Under a trend (roughly equivalent to BAU) scenario, a near linear decline in mean species abundance (MSA) out to 2050 was projected (van Vuuren et al. 2015). Projections of mean extinction risk for mammals and birds in southeast Asia, India, China, sub-Saharan Africa, and tropical South America under a 2060 BAU scenario (Tilman et al. 2017) indicated substantial increases in risk for animals of all sizes due to increasing cropland area, ultimately driven by population growth and changing incomes. The greatest increase in risk was associated with mammals in sub-Saharan Africa.

IIA.3. Biodiversity trends under alternative scenarios

31. Common to all three GBO-4 alternative scenarios (also described in CBD/SBSTTA/21/2, Paragraphs 38-42), relative to the BAU projections, were reductions in impacts on terrestrial species biodiversity (population sizes, Red List Index status, local species richness, and mean species abundance), and an increase in food crop production. In addition, halting deforestation and implementing reforestation were highlighted as making important contributions to both mitigating climate change and protecting biodiversity. Reductions in GHGs and an increase in energy efficiency were needed to meet climate goals, and moreover, biodiversity goals could only be achieved if a substantial deployment of biofuels was avoided. Transformation of systems of food production, distribution, and consumption could contribute towards both meeting human demands and reducing pressures and impacts on biodiversity. Other policy tools could include, among others, reducing ecosystem degradation and fragmentation, and reducing overexploitation.

32. In some cases, projections of terrestrial biodiversity to 2050 using alternative scenarios developed since GBO-4, identify ways to at least partially meet the 2050 Vision through specific policy choices. Negative interactions between climate change and land use change on biodiversity have been identified, as have potential positive interactions between climate change policy and biodiversity consequences, for example through reforestation. Further details are provided in the paragraphs below.

33. Visconti et al (2016) examined a ‘Consumption Change’ scenario[16], in which a set of sustainable development goals on climate change, biodiversity and human well-being were achieved through changes in production, consumption, waste, protected areas, and forestry, among others. This scenario showed a reduction in extinction risk, especially in the tropics, and a decline in population losses compared to BAU. Furthermore the policy mix under consideration also contributed towards meeting other societal development goals, suggesting that scenarios with ambitious longer-term policies can be compatible with near-term biodiversity goals (Visconti et al., 2016).

34. Newbold et al. (2015), examined biodiversity changes to 2095 under land use change scenarios associated with the various RCP scenarios. The strongest climate mitigation (low emissions) scenario[17] assumes substantial conversion of land to biofuels and other agriculture, and therefore led to a very negative outcome for biodiversity. However, the scenario associated with a medium level of climate mitigation[18] projected an increase in mean local richness relative to 2005; this scenario has carbon pricing leading to greater preservation of primary forest, and reforestation of secondary forest, thus highlighting potential interactions between climate change mitigation policies and biodiversity.

---

[16] IPCC SRES B1
[17] RCP2.6
[18] RCP4.5

35. A study to examine the effects of land use change on extinction risk in 2060 concluded that three proactive policies, namely closing yield gaps (moving from forecasted BAU yields towards attainable yields), reducing meat consumption relative to BAU, and increasing food imports to focus crop production in higher-yield regions, all reduced extinction risks for birds and mammals in sub-Saharan Africa, tropical South America, and southeast Asia, India, and China relative to BAU (Tilman et al. 2017). In combination, these three policies could offset about one half to two-thirds of projected 2060 BAU increases in extinction risk for large- and medium-sized birds and mammals.

36. Three 'challenge' scenarios, and the impacts of their policy measures on mean species abundance (MSA) were compared to a trend (BAU) scenario (van Vuuren et al. 2015). By 2050 the three scenarios could stabilize 'biodiversity loss' (proxied by MSA) at 2020 levels through increasing agricultural productivity, reducing consumption of meat and eggs, reducing waste, avoiding fragmentation, mitigating climate change, expanding protected areas, and other policies in differing combinations depending upon the scenario examined.

37. Climate change can exacerbate the impacts of habitat loss and fragmentation on biodiversity by increasing the susceptibility of fragmented populations to random events and hindering the ability of species to cope with land-cover changes. Using a statistical model of species vulnerability to land cover and climate change in conjunction with scenarios of climate change from the IPCC fourth assessment report and projections of land-cover change from three Millennium Ecosystem Assessment scenarios, Mantyka-Pringle et al. (2015) mapped the effect of this interaction. They found that future climate change could increase the impact of land-cover change on birds and mammals by 28%-43% and 9%-24%, respectively, depending on the specific scenario.

38. Efforts to mitigate climate change can exert an indirect effect on biodiversity since climate mitigation policies will influence land use decisions. Jantz et al. (2015) used RCP scenarios to assess the potential impact of climate policy on loss of habitable area in biodiversity hotspots due to necessitated land use change (but not including direct climate change impacts), and projected the potential extinctions that might result from these changes. Similarly to the Newbold et al. (2015) study, they found that relative to a high emissions scenario[19], low emissions[20] resulted in the next highest number of additional species extinctions (due to conversion of natural habitat for biofuels and to cropland), and medium-low[21] and medium emissions[22] the lowest.

IIB. Marine biodiversity status and trends

IIB.1. Current state of biodiversity and ecosystem services

39. The state of marine biodiversity as described in GBO4 can be briefly summarized as follows: An increasing proportion of fish stocks were overexploited, depleted or collapsed. However, there had been an increase in the proportion of fisheries certified as sustainable. Nutrient pollution remained a significant threat, though it had stabilized in some areas of Europe and North America. Other marine pollutants (such as chemicals and plastics) were increasing. The rate of species invasions was increasing. Pressures on coral reefs were increasing, and they remained at risk, though MPAs were covering a larger fraction of coral areas. More broadly, protected areas were spanning an increasing fraction of the ocean, though networks remained unrepresentative and some critical sites for biodiversity were poorly conserved. Combinations of anthropogenic drivers could push

---

[19] RCP8.5
[20] RCP2.6
[21] RCP4.5
[22] RCP6.0

regional social-ecological systems beyond tipping points and transition them to a new phase (e.g. reefs from coral dominated to macroalgae dominated) in which biodiversity and ecosystem services become severely impacted.

40. Current estimates of the state of marine ecosystems post-GBO4 suggest a continuation of the trends therein, in a similar manner to terrestrial systems. A key ecosystem service – fisheries production – has received important new updates suggesting no overall improvement in the state of global marine fish stocks (FAO 2016), and the global total production of wild capture fisheries has either slightly or substantially declined, depending on the study. Corals have endured an extremely lengthy bleaching event. Details are below.

41. *Species richness and abundance:* As in the terrestrial environment, trends in richness vary by scale and study. Local richness patterns showed considerable variation but no global mean trend over time, but there have been changes in community composition that may be consequences of climate change and biotic homogenization (Dornelas et al. 2014). The WWF Living Planet Index indicated a decline in the marine index[23] of 36% since 1970 (WWF 2016).

42. *Global fisheries:* The 2016 State of Fisheries and Aquaculture (SOFIA) report (FAO 2016) suggested that in 2014 aquaculture passed wild-capture fisheries in terms of contributing fish for human consumption for the first time. It noted that 31.4% of fish stocks were estimated to be overfished. The SOFIA report also indicated that production from wild capture fisheries has declined since the peak of 86 million tonnes in 1996 to around 80 million tonnes, while a catch reconstruction that also accounted for discards and illegal, unreported and unregulated fisheries suggested a much stronger decline but from a higher peak of production (Pauly and Zeller, 2016).

43. *Coral reef status:* Coral reefs form important natural ecosystems providing many goods and services – including food, tourism, and buffering against storms and surges. In addition, they are among the most biodiverse habitats on the planet. However, they are a particularly vulnerable habitat showing significant signs of degradation (Hughes et al., 2017). Tipping points exist at which coral reef ecosystems can shift to being dominated by macroalgae, with low resilience and an associated change and reduction in biodiversity and many ecosystem services they provide, such as reef-associated fisheries and tourism. They face multiple and considerable challenges from warming waters, pollution, ocean acidification, overexploitation and destructive fishing practices. A 2015-2017 coral bleaching event has been called ‘the longest and most widespread […] on record’[24].

IIB.2 Biodiversity trends under business as usual scenarios

44. The BAU scenario in GBO-4 indicated that climate change was projected to become a major driver of ecosystem and biodiversity impacts by 2050, with species impacted by global oceanic temperature increases, a decline of sea ice, ocean acidification, and rising sea levels. As in terrestrial regions, the movement of species to remain in favourable climates would impact ecosystem services and reduce the effectiveness of protected areas, as well as increase the risks of species extinction (Leadley et al., 2014). Pressures on wild-capture marine fisheries were projected to increase substantially in many regions, leading to the collapse of some exploited fish populations. However, an increase in fish production to meet global demand was projected to come about due to a rapid expansion in aquaculture, raising concerns about potential associated impacts including demand for high protein feed products, pollution, and further competition for space.

---

[23] Geometric mean change in abundance of populations

[24] https://coralreefwatch.noaa.gov/satellite/analyses_guidance/global_coral_bleaching_2014-17_status.php

45. The recent literature relating to trends and projections of biodiversity, ecosystem services, and vulnerable habitats in the marine realm under high-emissions or BAU scenarios suggests considerable changes in patterns of biodiversity by mid- to end-century. In particular, local marine species richness has been projected to increase globally due to species range expansions and invasions, but with high local extirpations, particularly in the tropics (García Molinos et al., 2015), and a mean latitudinal range shift of over 25km per decade (Jones and Cheung, 2015). By 2050, global fisheries are projected to decline in terms of the proportion of exploited species at or above a recovery target biomass, the catch potential, the revenue and the profit. Global marine primary productivity will likely decline by the end of the century, though there remains uncertainty about the magnitude of any decrease. Coral reefs are projected to continue to rapidly deteriorate, with regions currently occupied by reefs showing a decline in suitable area, resulting in large-scale consequences for ecosystem services such as tourism (in the billions of dollars) and fisheries. For details, see below.

46. Global patterns in marine richness forecasted under a high emissions scenario[25], which assumes that trends continue along current trajectories without strong mitigation efforts, suggested that by 2100 range expansions will exceed contractions (García Molinos et al., 2015), resulting in an overall increase in mean local richness (Fig. 2). This was projected to lead to changes in community composition, the homogenization of present-day ecological communities in some areas, and high extirpation rates, particularly at low latitudes. In general, there were projected to be species richness gains at high latitudes, while richness was lost near the equator. A separate assessment of changes in the global patterns of marine species richness under a high emissions[26] pathway out to 2050 indicated a mean poleward latitudinal shift in species ranges of 25.6 km per decade, with local extinctions again predicted to be concentrated near the equator, and invasions more concentrated at higher latitudes (Jones and Cheung, 2015). Such changes resulting from shifts in species distribution will affect the distribution and availability of commercially targeted species for fisheries, and may result in large-scale redistributions of fishing effort.

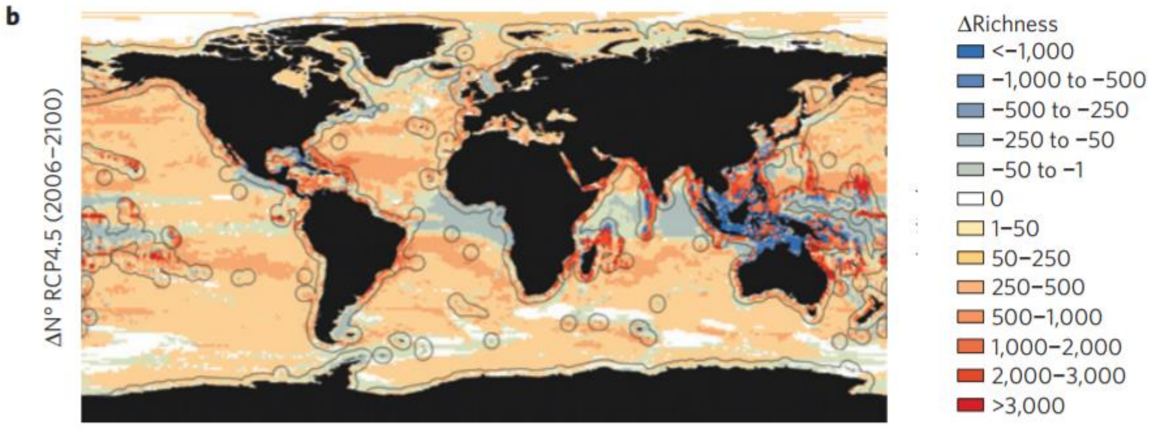

Fig. 2. Difference between 2006 and 2100 in marine species richness under a high emissions scenario[27]. From García Molinos et al. (2015).

47. A recent projection of global fisheries under an unchanged climate but BAU-management scenario (Costello et al., 2016) suggested that by 2050 the proportion of exploited fish stocks at or above a recovery target biomass will decline dramatically (from 47% today to 12% in 2050), as will the economic profit from the fisheries. A separate study by Lam et al. (2016) came to similar

---

[25] RCP8.5
[26] RCP8.5
[27] RCP8.5

conclusions, projecting that catch potential will decline by an average of 7.7%, while revenue will decline by 10.4% by 2050. Under a BAU-like scenario[28], Barange et al. (2014) predicted increased fish productivity at high latitudes and decreased productivity at low/mid latitudes by 2050, with overall potential production increasing by 3.4% (Barange et al., 2014). Marine primary productivity supports all fisheries, and ultimately all marine life, and the most recent multi-model projections of global marine primary productivity have suggested that there will be a decline to 2100 under a high-emissions[29] scenario (Bopp et al. 2013; Fu et al. 2016), though there remain large uncertainties (Laufkötter et al. 2015).

48. Using niche-based modelling, Descombes et al. (2015) forecasted future coral reef thermal suitability and identified locations that may be most vulnerable to climate change under a high-emissions[30] scenario. Projections indicated that relative to its current range (2005-2014), the total area suitable for coral reefs may change by around -2% to +9% by 2050, and 0%-16% by 2100. This expansion was due to an increase in thermally suitable habitats at high latitudes, although there are likely to be many factors limiting the abilities of coral to colonize such areas, particularly in rapid response to warming waters. Furthermore, when examining the range of areas currently occupied by coral reefs, a decline of -28% to -38% was forecasted by 2050, and -31% to –46% by 2100, suggesting that contemporary coral reefs hotspots will mismatch with areas of future suitability. Such a retreat of coral reefs from low latitudes would have serious consequences for the key ecosystem services that reefs provide, such as fisheries and tourism (Descombes et al., 2015). Using statistical correlation analyses, Chen et al. (2015) estimated that above 26.85°C sea surface temperature (SST), a reduction of global coral reef coverage by 2.3% could be expected with a 1% increase in SST. Furthermore, a 1% increase in carbon dioxide would result in a 0.6% reduction in coral coverage globally. Under a high-emissions scenario[31], this implied a substantial loss in coral coverage, and a consequent loss in tourism and recreation value of $5.8 billion by 2050 and $12 billion by 2095.

IIB.3 Biodiversity trends under alternative scenarios

49. In all three GBO4 alternative scenarios, the proportion of marine capture fishery stocks that would be overfished was lower than for the BAU scenario, with stronger management limiting overfishing and enabling stocks to rebuild. Furthermore, with changes in human diets and reductions of losses in the food system, demands on marine fisheries and aquaculture would also be reduced; changes in agricultural management could also reduce nutrient run-off and pollution into marine systems.

50. Mitigation and altered management scenarios developed since GBO-4 demonstrate substantial positive effects on future biodiversity and marine ecosystem services relative to BAU scenarios. For climate (not overfishing) mitigation, changes in the spatial patterns of species richness remained similar out to the mid-century, although with reduced species latitudinal movement rates. However, by the end of the century there were projected to be lower net local losses and reduced alteration in the makeup of biological communities (García Molinos et al., 2015). By 2050, some scenarios of strong fisheries management produced an increase in the proportion of exploited fish stocks near a recovery target biomass, and in total global fisheries profit, relative to both BAU-management and even the present day (Costello et al. 2016). A separate projection indicated a reduced (though still extant) decline in catch and revenue potential (Lam et al., 2016). Thus, strong mitigation can have a profound effect on both biodiversity and ecosystem services in

---

[28] IPCC SRES A1B; somewhere between RCP6.0 and RCP8.5 in terms of CO_2 concentration.
[29] RCP8.5
[30] RCP8.5
[31] RCP8.5

the global ocean. Furthermore, changes in fisheries management regimes can lead to multiple benefits for both biodiversity and economic productivity. However, coral reef habitats have been projected to continue to decline, though at a reduced rate, even under mitigation scenarios. Details are provided in the paragraphs below.

51. As an alternative to the high emissions[32] pathway, (García Molinos et al., 2015) also projected changes in global marine richness under a medium-low emissions pathway[33]. The distribution patterns of species invasions and extirpations started to diverge from the mid-century (2040-2065). By the end of the century, the general spatial pattern under medium-low emissions remained similar but with lower net local losses near the equator and less widespread changes in community composition (García Molinos et al., 2015). Jones and Cheung (2015) projected the mean rate of species range shifts to 2050 to be reduced from 25.6 km/decade to 15.5 km/decade under a low[34] versus high[35] emissions pathway, and furthermore reductions in invasions and local extirpations, though generally similar spatial patterns. Similarly, when warming was reduced from 3.5°C to the 1.5°C target of the Paris Agreement (Cheung et al., 2016), species turnover (rate of change in an area based on extinctions and immigrations) was reduced by more than 50%.

52. In terms of fisheries, applying management policy for maximizing sustainable yield (MSY) or maximising profit through rights-based fisheries management (RBFM) was projected to produce improvements in catch profit, and fish stock biomass relative to the BAU-management scenario (Costello et al. 2016)[36]. In particular, by 2050, the proportion of fish stocks above their target recovery biomass and the total profit exceeded that of the present day under both policies, and in fact greatly exceeded that of the 2050 BAU scenario (by $53 billion dollars annually in the case of fisheries profit for the RBFM scenario). Similarly, under a low emissions scenario[37], Lam et al. (2016) projected a 4% decline (versus 7.7% under high-emissions[38]) in catch potential and a 7.7% decline (versus 10.4%) in revenue potential by 2050, suggesting that mitigation policies can limit impacts. Cheung et al. (2016) estimated the benefits to global fisheries from meeting the 1.5°C warming target in the Paris Agreement were that every degree of warming above this target resulted in a projected 3 million metric tons reduction in potential catch. Strong climate mitigation[39] was projected to limit the decline in global net primary productivity relative to a high-emissions[40] scenario (Bopp et al. 2013).

53. Under the medium-low emissions[41] pathway, by 2050 the overall global area of suitable habitat for coral reefs was reduced relative to the high emissions[42] scenario, due to a relatively cooler global ocean. The decline in current areas of suitable habitat for coral occupancy was also reduced, indicating a still negative but relatively smaller impact on reefs and associated ecosystem services relative to the high-emissions pathway[43] (Descombes et al., 2015). The differential reduction in economic value associated with coral reefs under mitigation pathways (low, medium-low, and medium emissions[44]) has been forecasted to be substantial (Chen et al., 2015), representing a loss

---

[32] RCP8.5
[33] RCP4.5
[34] RCP2.6
[35] RCP8.5
[36] Note that this study only looks at the impacts of management changes, not of climate change or other stressors.
[37] RCP2.6
[38] RCP8.5
[39] RCP2.6
[40] RCP8.5
[41] RCP4.5
[42] RCP8.5
[43] RCP8.5
[44] Corresponding to RCPs 2.6, 4.5, and 6.0

of between \$3-\$4.3 billion by 2050 (versus \$5.8 billion under high-emissions[45]), and \$2-\$8.1 billion by 2050 (versus \$12 billion).

IIC. Freshwater biodiversity status and trends

54. GBO4 found relatively little material exists on status and trends in freshwater biodiversity at a global scale. Nutrient pollution remains a significant threat to freshwater ecosystems, though has stabilized in some areas of Europe and North America. Other pollutants such as pesticides and chemicals are increasing.

55. The BAU scenario in GBO4 indicated global water withdrawals from freshwater systems were projected to almost double, the majority going towards food production, reducing the flow of water for freshwater ecosystems (Leadley et al., 2014).

56. Relatively few post-GBO4 studies of global patterns in freshwater biodiversity exist. The freshwater LPI (WWF 2016) showed a greater reduction in index value[46] in the present day (down by 81% relative to 1970) relative to marine and terrestrial habitats. Changes in air temperature and precipitation, primarily due to increases in GHGs, have been predicted to have a significant impact on the temperature and hydrology of freshwater systems, and most species are narrowly adapted to the physical conditions of their freshwater environment (Knouft and Ficklin, 2017). While there are few global studies of trends in freshwater biodiversity, in the United States land use intensity within the distribution range of range-restricted freshwater fish species has been projected to increase by 3%-44% by 2051, depending on the land use scenario (Januchowski-Hartley et al., 2016). The number of range-restricted species with >30% of their distribution area occupied by intensive land use was projected to climb from 14% to 27%-58% between 2001 and 2051. A study of European catchments assessing climate change threats for multiple species of freshwater plants and animals projected that by 2050 habitat suitability would decrease significantly throughout the range for most freshwater species, with 59% of species predicted to lose more than half of their habitat suitability (Markovic et al., 2014).

III. GAPS AND UNCERTAINTIES

57. This review of status, trends, and projections subsequent to GBO4 has highlighted a number of gaps in projections and scenarios, as well as specific areas of uncertainty, that still remain. These are relevant to the 2050 Vision, and we describe these here.

58. Clear gaps exist in terms of projections of some aspects of global-scale biodiversity out to 2050 or beyond. In terms of habitats, freshwater biodiversity projections are sorely lacking (IPBES, 2016) and currently appear only to be available at regional or continental scales. Projections of trends in genetic biodiversity are lacking in all environments, with global spatially explicit maps only recently appearing for present-day biodiversity. Projections of changes in functional richness and of under-represented taxa (generally invertebrates) are also lacking. Quantification of anthropogenically-driven extinction rates relative to background rates also remains challenging, with the Red List Index or other approaches frequently being used as proxies. In terms of ecosystem services, the marine environment contains numerous recent projections for fisheries and services including coral reef tourism. However, terrestrially, recent projections of pollinators exist but explicit forecasts for other ecosystem services and functions at global scales remain limited, though links between biodiversity and ecosystem services have been demonstrated experimentally. Projections of ecosystem stability and regime shifts are also generally lacking,

---

[45] RCP8.5

[46] Representing the geometric mean of species abundances.

potentially due to the challenges inherent in forecasting these non-linear phase transitions, although there has been more work on this in marine systems and particularly coral reefs.

59. Of key relevance to the 2050 Vision is that, in a post-Paris-agreement world, current trends suggest a warming of about 3°C by 2100 (corresponding more closely to the medium-low[47] or medium[48] emissions scenarios), rather than the 4°C or more expected from the high emissions scenarios that are often characterised as BAU. Unfortunately, not all studies included medium-low and medium emission scenarios, and often preferred to focus on low[49] and high[50] emissions scenarios as bracketing a broad range of potential futures. We recommend that global biodiversity and ecosystem studies of land use and/or climate change impacts include all emissions scenarios, rather than just the highest and the lowest, as this will enhance their relevance for both the 2050 Vision and beyond. Further, at present there are very few studies that specifically examine 1.5°C climate scenarios (though see Cheung et al. 2016).

60. One key challenge for marine ecosystem projections is that the SSP scenarios do not have direct ‘narrative’ outcomes for marine ecosystems; that is, they do not have specific representation of processes such as marine fisheries, demand for fishes, market changes for marine goods, governance or representation of marine management policy alternatives. Newly developed narrative storylines for the marine realm include the Oceanic System Pathways (OSPs) (Maury et al., 2017), which have begun the process of developing these narratives and providing more detail of the socio-economic forces that will affect human impacts on marine ecosystems into the future. However, challenges remain. For example, at present these narratives are not yet linked via explicit scenarios to impact modelling efforts that produce quantitative projections (Tittensor et al., 2017). Furthermore, the need for local and regional scale operationalizable scenarios, either developed from the ground-up or downscaled from global scenarios, is critical, as this is the level at which many marine management decisions are made.

61. Furthermore, there is a need to harmonize terrestrial scenarios at global scales (to ensure compatibility between trajectories of land use change and climate across multiple sets of scenarios), and to harmonize marine and terrestrial scenarios to ensure consistency of developmental pathways. This will be especially critical for questions of food security, and it is notable how few studies simultaneously consider ecosystem services such as food supply across both marine and terrestrial systems (but see Blanchard et al., 2017).

62. For some aspects of biodiversity, there remains considerable variation between studies and models in terms of projections. Whilst some of this might come down to differences in models, it may also be due to variation in forcing scenarios, data inputs and model outputs. This highlights a gap in biodiversity and ecosystem forecasts that in the climate science community has been filled through ‘ensemble projections’, which force multiple models with the same pathways, scenarios, and model inputs, and has the models produce common outputs, which can then provide a mean across a suite of models and a more informative assessment of uncertainty around projections, as forcings and outputs are consistent. Such initiatives are beginning to appear for biodiversity and ecosystem service projections (e.g. the Fisheries and Marine Ecosystem Model Intercomparison Project (Tittensor et al., 2017)), but are in their relative infancy.

63. In part, the need for feedbacks between biodiversity and other sectors, including socio-ecological feedbacks, may be met through the work of the IPBES Scenarios and Models Expert Group, which

---

[47] RCP4.5
[48] RCP6.0
[49] RCP2.6
[50] RCP8.5

are developing a new suite of biodiversity scenarios (Rosa et al., 2017). These scenarios will link multiple spatial scales, from the local to the global, and describe narratives that link biodiversity, ecosystem services, and society in a circular (rather than linear) manner. These ‘visions for nature futures’ will be constructed in consultation with stakeholders from multiple sectors, including civil society, the private sector, policy and decision makers, indigenous knowledge groups, and others. They will use a range of approaches to identify pathways to achieve outcomes across multiple sectors (urban, agricultural, forestry, fisheries, and other), and consider actions and responses at both the individual and institutional scale. Furthermore, there is also a collaborative effort coordinated by the IPBES expert group on applying various models to a common subset of RCP/SSP combinations, in support of the IPBES Global Assessment. There has also been an international Belmont Forum / Biodiversa funding call on similar issues and relevant to the recommendations from the IPBES Methodological Assessment of Scenarios and Models. Such futures could be relevant to exploring pathways to the 2050 Vision, as well as other biodiversity-relevant targets.

IV. RELEVANCE OF RECENT PROJECTIONS FOR THE 2050 VISION

64. Notwithstanding the gaps identified above, many of the post-GBO4 projections and scenario explorations can be used in support of the post-2020 global biodiversity framework, and in particular the 2050 Vision. Many projections explicitly include 2050 or the mid-century as a specific time at which to examine changes across scenarios. While identifying what BAU corresponds to in the post-Paris Agreement context represents an ongoing effort (see paragraph 59), a few studies explicitly examine a world of 1.5°C warming relative to pre-industrial, and the RCPs and SSPs provide a range of potential futures from high mitigation to high emissions. Most studies compare multiple pathways and project the differences between them, typically including a pathway that can at least approximate BAU, thus demonstrating the existence a range of plausible societal futures. Furthermore, some studies identify the relative importance of specific policy or management decisions (e.g. fisheries, land use, or climate mitigation), and can thus be particularly useful in informing potential pathways to the 2050 Vision. Although scenario gaps exist, such as narratives for the marine realm, and feedbacks between biodiversity and socio-ecological systems, initiatives are in place to fill these gaps and thus the situation should ease in the not-too-distant future.

65. The projections summarized above suggest that under BAU scenarios that approximate high-emissions and/or high land use change and continued overfishing, biodiversity and ecosystem services will in general remain a considerable distance from the ideal encapsulated in the 2050 Vision. Current trends suggest a broad-scale loss of biodiversity in terms of population abundances and extinctions, though local species richness may actually increase in some places due to range expansions and species invasions. However, the composition of communities is likely to change substantially, and novel and unpredictable ecological assemblages will become more common. Significant declines in the abundance of many species are likely. Global fisheries are likely to decline in terms of potential catches, revenues, and profits. Coral reefs are likely to continue to steeply degrade, with concomitant impacts on services such as reef-associated fisheries and tourism. Insufficient information on freshwater biodiversity exists to assess trends at a global scale. Thus, under a high emissions pathway, we will remain a long way from the 2050 Vision of restoring, conserving, valuing, and wisely-using biodiversity, and maintaining ecosystem services and benefits.

66. Alternative scenarios and pathways suggest that meeting the 2050 Vision is at least generally plausible, but will require transformational change in terms of society or societal policies. Reductions in extinction risk and stabilizing declines in biodiversity and ecosystem services may

be met through a combination of societal and individual changes and policy choices, including mitigating climate change, increasing agricultural productivity, reducing consumption and waste, expanding protected areas, changing fisheries management approaches. Some scenarios (e.g. changes in fisheries management) may result in substantial improvements in a specific ecosystem service and associated economic output. No single scenario or projection examined changes across marine and terrestrial systems, and all facets of biodiversity and ecosystem services, so efforts to meet the 2050 Vision will require a mix of policies and institutional and societal changes derived from multiple existing scenarios, and will need to ensure their mutual coherence and that the benefits to biodiversity and ecosystems remain under any given mix. One aspect that appears necessary to avoid is a rapid expansion of land for growing biofuels, which while potentially mitigating climate impacts has deleterious consequences for terrestrial biodiversity and the total area of natural land. It also appears unlikely that coral reefs will reverse a trend of degradation under most plausible scenarios. Thus, in general it appears that the 2050 Vision may potentially be met for most, though perhaps not all, aspects of biodiversity, through a combination of the societal transformations described in this document.

67. Many of the recent studies assembled above could be of use when assessing how to meet multiple international targets of both societal development and biodiversity. Some studies explicitly highlight the Sustainable Development Goals (SDGs), and in particular the biodiversity aspects. Many, though not all, studies provide a continuous timeline of change under multiple scenarios, so relevant dates such as 2030 and 2050 can be extracted and compared. The 2050 Vision is focussed on biodiversity, and hence of most relevance to Sustainable Development Goals 13 and 14, though as biodiversity underpins sustainable development, many other goals are indirectly linked. The 2050 Vision appears consistent with meeting SDGs 13 and 14, though trade-offs between biodiversity and other SDGs have not been broadly explored. Initiatives such as The World in 2050 (TWI2050), which aims to ‘provide fact-based knowledge to support the policy process and implementation of the 2030 Agenda’ are also relevant for assessing the best pathways to achieve all SDGs with the minimum of trade-offs, and when moving from the 2030 SDGs to the 2050 Vision and beyond. The goal for 2050 and beyond in TWI2050 is social and economic sustainability within a stable earth system through a ‘sustainability transformation’ that maintains the human enterprise within planetary boundaries. The pathways identified through TWI2050 may be useful in achieving the 2050 Vision within a broad human-development context. Similarly, the biodiversity-centric scenarios under development by IPBES will be of relevance in terms of positioning ecosystems as a central feature of scenarios (rather than an outcome), and thus likely to be of use for examining pathways towards the 2050 Vision.

68. The post-2020 global biodiversity framework necessarily reflects the key 2030 and 2050 dates. From the scientific studies surveyed in this document, the 2050 Vision may act as a longer-term ‘context’ for the 2030 SDGs, particularly those focussed around biodiversity, and could be considered part of an even longer-term strategy for biodiversity by providing a stepping-stone towards 2100 and beyond.

V. REFERENCES

Barange, M., Merino, G., Blanchard, J. L., Scholtens, J., Harle, J., Allison, E. H., Allen, J. I., Holt, J. and Jennings, S.: Impacts of climate change on marine ecosystem production in societies dependent on fisheries, Nat. Clim. Chang., 4(3), 211–216, doi:10.1038/NCLIMATE2119, 2014.

Blanchard, J. L., Watson, R. A., Fulton, E. A., Cottrell, R. S., Nash, K. L., Bryndum-Buchholz, A., Büchner, M., Carozza, D. A., Cheung, W. W. L., Elliott, J., Davidson, L. N. K., Dulvy, N. K., Dunne, J. P., Eddy, T. D., Galbraith, E., Lotze, H. K., Maury, O., Müller, C., Tittensor, D. P. and Jennings, S.: Linked sustainability challenges and trade-offs among fisheries, aquaculture and agriculture, Nat. Ecol. Evol., 1(9), 1240–1249, doi:10.1038/s41559-017-0258-8, 2017.

Bopp, L., Resplandy L., Orr, J. C., Doney, S. C., Dunne, J. P., Gehlen, M., Halloran, P., Heinze, C., Ilyina, T., Sefreian, R., Tjiputra, J. and Vichu, M.: Multiple stressors of ocean ecosystems in the 21st century: projections with CMIP5 models, Biogeosci., 10, 6225-6245, 2013.

Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P., Narwani, A., Mace, G. M., Tilman, D., Wardle, D. A., Kinzig, A. P., Daily, G. C., Loreau, M., Grace, J. B., Larigauderie, A., Srivastava, D. S. and Naeem, S.: Biodiversity loss and its impact on humanity, Nature, 486: 59-67, 2012.

Chaudhary, A. and Brooks, T. M.: National consumption and global trade impacts on biodiversity, World Dev., *in press*.

Chen, P.-Y., Chen, C.-C., Chu, L. and McCarl, B.: Evaluating the economic damage of climate change on global coral reefs, Glob. Environ. Chang., 30(Supplement C), 12–20, doi:https://doi.org/10.1016/j.gloenvcha.2014.10.011, 2015.

Cheung, W. W. L., Reygondeau, G. and Frölicher, T. L.: Large benefits to marine fisheries of meeting the 1.5°C global warming target, Science (80-.)., 354(6319), 1591–1594, doi:10.1126/science.aag2331, 2016.

Costello, C., Ovando, D., Clavelle, T., Strauss, C. K., Hilborn, R., Melnychuk, M. C., Branch, T. A., Gaines, S. D., Szuwalski, C. S., Cabral, R. B., Rader, D. N. and Leland, A.: Global fishery prospects under contrasting management regimes, , doi:10.1073/pnas.1520420113, 2016.

De Vos, J. M., Joppa, L. N., Gittleman, J. L., Stephens, P. R. and Pimm, S. L.: Estimating the normal background rate of species extinction, Conserv. Biol., 29(2), 452–462, doi:10.1111/cobi.12380, 2015.

Descombes, P., Wisz, M. S., Leprieur, F., Parravicini, V., Heine, C., Olsen, S. M., Swingedouw, D., Kulbicki, M., Mouillot, D. and Pellissier, L.: Forecasted coral reef decline in marine biodiversity hotspots under climate change, Glob. Chang. Biol., 21(7), 2479–2487, doi:10.1111/gcb.12868, 2015.

Diversity, S. of the C. on B.: Global Biodiversity Outlook 4, Montreal., n.d.

Dornelas, M., Gotelli, N. J., McGill, B., Shimadzu, H., Moyes, F., Sievers, C. and Magurran, A. E.: Assemblage time series reveal biodiversity change but not systematic loss, Science (80-.)., 344(6181), 296–299, 2014.

Duffy, J. E., Godwin, C. M. and Cardinale, B. J.: Biodiversity effects in the wild are common and as strong as key drivers of productivity, Nature, 549, 261-264, 2017.

FAO: The State of World Fisheries and Aquaculture 2016, [online] Available from:

http://www.fao.org/3/a-i5555e.pdf (Accessed 8 November 2017), 2016.

Fu, W., Randerson, J. T. and Moore, J. K.: Climate change impacts on net primary production (NPP) and export production (EP) regulated by increasing stratification and phytoplankton community structure in the CMIP5 models, Biogeosci., 13, 5151-5170, 2016.

García Molinos, J., Halpern, B. S., Schoeman, D. S., Brown, C. J., Kiessling, W., Moore, P. J., Pandolfi, J. M., Poloczanska, E. S., Richardson, A. J. and Burrows, M. T.: Climate velocity and the future global redistribution of marine biodiversity, Nat. Clim. Chang., 6(1), 83–88, doi:10.1038/nclimate2769, 2015.

Hallmann, C. A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., Stenmans, W., Müller, A., Sumser, H., Hörren, T., Goulson, D. and de Kroon, H.: More than 75 percent decline over 27 years in total flying insect biomass in protected areas, edited by E. G. Lamb, PLoS One, 12(10), e0185809, doi:10.1371/journal.pone.0185809, 2017.

Harrison, P. A., Berry, P. M., Simpson, G., Haslett, J. R., Blicharska, M., Bucur, M., Dunford, R., Egoh, B., Garcia-Llorente, M., Geamana, N., Geertsema, W., Lommelen, E. Meiresonne, L. and Turkelboom, F.: Linkages between biodiversity attributes and ecosystem services: a systematic review, Ecosys. Serv., 9, 191-203: 2014.

Hughes, T. P., Barnes, M. L., Bellwood, D. R., Cinner, J. E., Cumming, G. S., Jackson, J. B. C., Kleypas, J., van de Leemput, I. A., Lough, J. M., Morrison, T. H., Palumbi, S. R., van Nes, E. H. and Scheffer, M.: Coral reefs in the Anthropocene, Nature, 546(7656), 82–90, doi:10.1038/nature22901, 2017.

IPBES: The Methodological assessment report on scenarios and models of biodiversity and ecosystem services., Bonn, Germany., 2016.

IUCN: The IUCN Red List of Threatened Species. Version 2017-2. [online] Available from: www.iucnredlist.org, 2017.

Jantz, S. M., Barker, B., Brooks, T. M., Chini, L. P., Huang, Q., Moore, R. M., Noel, J. and Hurtt, G. C.: Future habitat loss and extinctions driven by land use change in biodiversity hotspots under four scenarios of climate-change mitigation, Conserv. Biol., 29(4), 1122–1131, doi:10.1111/cobi.12549, 2015.

Januchowski-Hartley, S. R., Holtz, L. A., Martinuzzi, S., McIntyre, P. B., Radeloff, V. C. and Pracheil, B. M.: Future land use threats to range-restricted fish species in the United States, Divers. Distrib., 22(6), 663–671, doi:10.1111/ddi.12431, 2016.

Jones, M. C. and Cheung, W. W. L.: Multi-model ensemble projections of climat change effects on global marine biodiversity, ICES J, 72(3), 741–752, 2015.

Knouft, J. H. and Ficklin, D. L.: The Potential Impacts of Climate Change on Biodiversity in Flowing Freshwater Systems, Annu. Rev. Ecol. Evol. Syst., 48(1), annurev-ecolsys-110316-022803, doi:10.1146/annurev-ecolsys-110316-022803, 2017.

Lam, V. W. Y., Cheung, W. W. L., Reygondeau, G. and Sumaila, U. R.: Projected change in global fisheries revenues under climate change, Sci. Rep., 6(1), 32607, doi:10.1038/srep32607, 2016.

Laufkötter, C., Vogt, M., Gruber, N., Aita-Noguchi, M., Aumont, O., Bopp, L., Buitenhuis, E., Doney,

S. C., Dunne, J., Hashioka, T., Hauck, K., Hirata, T., John, J., Le Quéré, C., Lima, I. D., Nakano, H., Seferian R., Totterdell, I., Vichi, M., and Völker, C.: Drivers and uncertainties of future global marine primary production in marine ecosystem models, Biogeosci., 12, 6955-6984, 2015.

Leadley, P. W., Krug, C. B., Alkemade, R., Pereira, H. M., Sumaila, U. R., Walpole, M., Marques, A., Newbold, T., Teh, L. S. L., Kolck, J., Bellard, C., Januchowski-Hartley, S. R. and Mumby, P. J.: Progress towards the Aichi biodiversity targets: an assessment of biodiversity trends, policy scenarios and key actions, Global Biodiversity Outlook 4 (GBO-4) Technical Report, [online] Available from: http://www.cbd.int/ (Accessed 9 November 2017), 2014.

Mantyka-Pringle, C. S. Visconti, P., Di Marco, M., Martin, T. G., Rondinini, C. and Rhodes, J. R.: Climate change modifies risk of global biodiversity loss due to land-cover change, Biol. Conserv., 187, 103–111, doi:10.1016/J.BIOCON.2015.04.016, 2015.

Markovic, D., Carrizo, S., Freyhof, J., Cid, N., Lengyel, S., Scholz, M., Kasperdius, H. and Darwall, W.: Europe’s freshwater biodiversity under climate change: distribution shifts and conservation needs, edited by D. Richardson, Divers. Distrib., 20(9), 1097–1107, doi:10.1111/ddi.12232, 2014.

Maury, O., Campling, L., Arrizabalaga, H., Aumont, O., Bopp, L., Merino, G., Squire, D., Cheung, W., Goujon, M., Guivarch, C., Lefort, S., Marsac, F., Monteagudo, P., Murtugudde, R., Őösterblom, H., Pulvenis, J. F., Ye, Y. and van Ruijven, B. J.: From shared socio-economic pathways (SSPs) to oceanic system pathways (OSPs): Building policy-relevant scenarios for global oceanic ecosystems and fisheries, Glob. Environ. Chang., 45, 203–216, doi:10.1016/J.GLOENVCHA.2017.06.007, 2017.

Miraldo, A., Li, S., Borregaard, M. K., Flórez-Rodríguez, A., Gopalakrishnan, S., Rizvanovic, M., Wang, Z., Rahbek, C., Marske, K. A. and Nogués-Bravo, D.: An Anthropocene map of genetic diversity., Science, 353(6307), 1532–1535, doi:10.1126/science.aaf4381, 2016.

Newbold, T., Hudson, L. N., Hill, S. L. L., Contu, S., Lysenko, I., Senior, R. A., Börger, L., Bennett, D. J., Choimes, A., Collen, B., Day, J., De Palma, A., Díaz, S., Echeverria-Londoño, S., Edgar, M. J., Feldman, A., Garon, M., Harrison, M. L. K., Alhusseini, T., Ingram, D. J., Itescu, Y., Kattge, J., Kemp, V., Kirkpatrick, L., Kleyer, M., Correia, D. L. P., Martin, C. D., Meiri, S., Novosolov, M., Pan, Y., Phillips, H. R. P., Purves, D. W., Robinson, A., Simpson, J., Tuck, S. L., Weiher, E., White, H. J., Ewers, R. M., Mace, G. M., Scharlemann, J. P. W. and Purvis, A.: Global effects of land use on local terrestrial biodiversity, Nature, 520(7545), 45–50, doi:10.1038/nature14324, 2015.

Newbold, T., Hudson, L. N., Arnell, A. P., Contu, S., De Palma, A., Ferrier, S., Hill, S. L. L., Hoskins, A. J., Lysenko, I., Phillips, H. R. P., Burton, V. J., Chng, C. W. T., Emerson, S., Gao, D., Pask-Hale, G., Hutton, J., Jung, M., Sanchez-Ortiz, K., Simmons, B. I., Whitmee, S., Zhang, H., Scharlemann, J. P. W. and Purvis, A.: Has land use pushed terrestrial biodiversity beyond the planetary boundary? A global assessment., Science, 353(6296), 288–91, doi:10.1126/science.aaf2201, 2016.

O’Neill, B. C., Kriegler, E., Riahi, K., Ebi, K. L., Hallegatte, S., Carter, T. R., Mathur, R. and Vuuren, D. P.: A new scenario framework for climate change research: the concept of shared socioeconomic pathways, Clim. Change, 122(3), 387–400, doi:10.1007/s10584-013-0905-2, 2013.

Pauly, D. and Zeller, D.: ARTICLE Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining, Nat. Commun., 7, doi:10.1038/ncomms10244, 2016.

Pecl, G. T., Araújo, M. B., Bell, J. D., Blanchard, J., Bonebrake, T. C., Chen, I.-C., Clark, T. D., Colwell, R. K., Danielsen, F., Evengård, B., Falconi, L., Ferrier, S., Frusher, S., Garcia, R. A., Griffis, R. B., Hobday, A. J., Janion-Scheepers, C., Jarzyna, M. A., Jennings, S., Lenoir, J., Linnetved, H. I., Martin, V. Y., McCormack, P. C., McDonald, J., Mitchell, N. J., Mustonen, T., Pandolfi, J. M., Pettorelli, N., Popova, E., Robinson, S. A., Scheffers, B. R., Shaw, J. D., Sorte, C. J. B., Strugnell, J. M., Sunday, J. M., Tuanmu, M.-N., Vergés, A., Villanueva, C., Wernberg, T., Wapstra, E. and Williams, S. E.: Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being., Science, 355(6332), eaai9214, doi:10.1126/science.aai9214, 2017.

Regan, E. C., Santini, L., Ingwall-King, L., Hoffmann, M., Rondinini, C., Symes, A., Taylor, J. and Butchart, S. H. M.: Global Trends in the Status of Bird and Mammal Pollinators, Conserv. Lett., 8(6), 397–403, doi:10.1111/conl.12162, 2015.

Rosa, I. M. D., Pereira, H. M., Ferrier, S., Alkemade, R., Acosta, L. A., Akcakaya, H. R., den Belder, E., Fazel, A. M., Fujimori, S., Harfoot, M., Harhash, K. A., Harrison, P. A., Hauck, J., Hendriks, R. J. J., Hernández, G., Jetz, W., Karlsson-Vinkhuyzen, S. I., Kim, H., King, N., Kok, M. T. J., Kolomytsev, G. O., Lazarova, T., Leadley, P., Lundquist, C. J., García Márquez, J., Meyer, C., Navarro, L. M., Nesshöver, C., Ngo, H. T., Ninan, K. N., Palomo, M. G., Pereira, L. M., Peterson, G. D., Pichs, R., Popp, A., Purvis, A., Ravera, F., Rondinini, C., Sathyapalan, J., Schipper, A. M., Seppelt, R., Settele, J., Sitas, N. and van Vuuren, D.: Multiscale scenarios for nature futures, Nat. Ecol. Evol., 1(10), 1416–1419, doi:10.1038/s41559-017-0273-9, 2017.

Secretariat of the Convention on Biological Diversity: Global biodiversity outlook 4. Montréal, Canada, 155 pages, 2014.

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., de Vries, W., de Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B. and Sörlin, S.: Planetary boundaries: Guiding human development on a changing planet, Science (80-.)., 347(6223) [online] Available from: http://science.sciencemag.org/content/347/6223/1259855.abstract, 2015.

Tilman, D., Clark, M., Williams, D. R., Kimmel, K., Polasky S. and Packer, C.: Future threats to biodiversity and pathways to their prevention, Nature, 546, 73-81, 2017.

Tittensor, D. P., Eddy, T. D., Lotze, H. K., Galbraith, E. D., Cheung, W., Barange, M., Blanchard, J. L., Bopp, L., Bryndum-Buchholz, A., Büchner, M., Bulman, C., Carozza, D. A., Christensen, V., Coll, M., Dunne, J. P., Fernandes, J. A., Fulton, E. A., Hobday, A. J., Huber, V., Jennings, S., Jones, M., Lehodey, P., Link, J. S., Mackinson, S., Maury, O., Niiranen, S., Oliveros-Ramos, R., Roy, T., Schewe, J., Shin, Y.-J., Stock, C. A., Underwood, P. J., Volkholz, J., Watson, J. R. and Walker, N. D.: A protocol for the intercomparison of marine fishery and ecosystem models: Fish-MIP v1.0, Geosci. Model Dev. Discuss., 2017, 1–39, doi:10.5194/gmd-2017-209, 2017.

Vellend, M., Baeten, L., Myers-Smith, I. H., Elmendorf, S. C., Beauséjour, R., Brown, C. D., De Frenne, P., Verheyen, K. and Wipf, S.: Global meta-analysis reveals no net change in local-scale plant biodiversity over time., Proc. Natl. Acad. Sci. U. S. A., 110(48), 19456–9, doi:10.1073/pnas.1312779110, 2013.

Velland, M. Dornelas, M., Baeten, L., Beausejour, R., Brown, C. D., De Frenne, P., Elmentdorf, S. C., Gotelli, N. J., Moyes, F., Myers-Smith, I. H., Magurran, A. E., McGill, B. J., Shimadzu, H. and Sievers C.: Estimates of local biodiversity change over time stand up to scrutiny, Ecology, 98(2), 583-590, 2017.

Visconti, P., Bakkenes, M., Baisero, D., Brooks, T., Butchart, S. H. M., Joppa, L., Alkemade, R., Di Marco, M., Santini, L., Hoffmann, M., Maiorano, L., Pressey, R. L., Arponen, A., Boitani, L., Reside, A. E., van Vuuren, D. P. and Rondinini, C.: Projecting Global Biodiversity Indicators under Future

Development Scenarios, Conserv. Lett., 9(1), 5–13, doi:10.1111/conl.12159, 2016.

van Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G. C., Kram, T., Krey, V., Lamarque, J.-F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S. J. and Rose, S. K.: The representative concentration pathways: an overview, Clim. Change, 109(1–2), 5–31, doi:10.1007/s10584-011-0148-z, 2011.

van Vuuren, D. P., Kok, M., Lucas, P. L., Gerdien Prins, A. , Alkemade, R., van den Berg, M., Bouwman, L., van der Esch, S., Jeuken, M., Kram, T. and Stehfest, E.: Pathways to achieve a set of ambitious global sustainability objectives by 2050: Explorations using the IMAGE integrated assessment model, Technol. Forecast. Soc. Change, 98, 303–323, doi:10.1016/J.TECHFORE.2015.03.005, 2015.

Watson, J. E. M., Jones, K R., Fuller, R. A., Di Marco, M., Segan, D. B., Butchart, S. H. M., Allan, J. R., McDonald-Madden, E. and Venter, O.: Persistent disparities between recent rates of habitat conversion and protection and implications for future global conservation targets, Cons. Lee., 9(6), 413-421, 2016.

WWF: Living Planet Report 2016, Gland, Switzerland., 2016.
