Towards a better future for biodiversity and people: modelling Nature Futures

HyeJin Kim^{*1,2,3}, Garry D. Peterson⁴, William W. L. Cheung⁵, Simon Ferrier⁶, Rob Alkemade^{7,8}, Almut Arneth⁹, Jan J. Kuiper⁴, Sana Okayasu⁷, Laura Pereira^{4,10,11}, Lilibeth A. Acosta¹², Rebecca Chaplin-Kramer^{13,14,15}, Eefje den Belder^{7,16}, Tyler D. Eddy¹⁷, Justin A Johnson¹⁸, Sylvia Karlsson-Vinkhuyzen¹⁹, Marcel T.J. Kok⁷, Paul Leadley²⁰, David Leclère²¹, Carolyn J. Lundquist^{22,23}, Carlo Rondinini^{24,25}, Robert J. Scholes¹⁰, Machteld A. Schoolenberg⁷, Yunne-Jai Shin²⁶, Elke Stehfest⁷, Fabrice Stephenson²⁷, Piero Visconti²¹, Detlef van Vuuren^{7,11}, Colette C.C. Wabnitz^{5,28}, Juan José Alava⁵, Ivon Cuadros-Casanova²⁴, Kathryn K. Davies^{22,29}, Maria A. Gasalla³⁰, Ghassen Halouani³¹, Mike Harfoot³², Shizuka Hashimoto³³, Thomas Hickler^{34,35}, Tim Hirsch³⁶, Grigory Kolomytsev³⁷, Brian W. Miller³⁸, Haruka Ohashi³⁹, Maria Gabriela Palomo⁴⁰, Alexander Popp⁴¹, Roy Paco Remme^{13,42}, Osamu Saito⁴³, U. Rashid Sumalia^{5,44}, Simon Willcock^{45,46}, Henrique M. Pereira^{*1,2,47}

*Corresponding authors: HyeJin Kim, Henrique Pereira

German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig

Puschstrasse 4, 04103 Leipzig, Germany

UK Centre for Ecology and Hydrology

Library Ave, Bailrigg, Lancaster LA1 4AP, United Kingdom

hkim@ceh.ac.uk, henrique.pereira@idiv.de

+44 (0)1524 595866

¹ German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Leipzig, Germany

² Martin Luther University Halle-Wittenberg, Halle (Salle), Germany

³ UK Centre for Ecology and Hydrology, Library Ave, Bailrigg, Lancaster LA1 4AP, United Kingdom

⁴ Stockholm Resilience Centre, Stockholm University, Sweden

⁵ Institute for the Oceans and Fisheries, University of British Columbia, Vancouver, Canada

⁶ CSIRO Land and Water, Canberra, Australia

⁷ PBL Netherlands Environmental Assessment Agency, The Hague, Netherlands

⁸ Environmental Systems Analysis Group, Wageningen University, The Netherlands

⁹ KIT, Atmospheric Environmental Research, Garmisch-Partenkirchen, Germany

¹⁰ Global Change Institute, University of the Witwatersrand, South Africa

¹¹ Copernicus Institute of Sustainable Development, Utrecht University, The Netherlands

¹² Climate Action and Inclusive Development Department, Global Green Growth Institute, Seoul, South Korea

¹³ Natural Capital Project, Stanford University, Stanford, CA, USA

¹⁴ Institute on the Environment, University of Minnesota, St Paul, MN, USA

¹⁵ Global Science, WWF. 131 Steuart St, San Francisco, CA, USA

¹⁶ Agrosystems Research, Wageningen University, The Netherlands

¹⁷ Centre for Fisheries Ecosystems Research, Fisheries & Marine Institute, Memorial University, St. John's, NL, Canada

- ¹⁸ Department of Applied Economics, University of Minnesota, USA
- ¹⁹ Public Administration and Policy Group, Wageningen University & Research, The Netherlands
- ²⁰ Ecologie, Systématique et Evolution, Université Paris-Saclay, CNRS, AgroParisTech, Orsay, France
- ²¹ Biodiversity and Natural Resources (BNR) Program, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria
- ²² National Institute of Water and Atmospheric Research (NIWA), Hamilton, New Zealand
- ²³ School of Environment, University of Auckland, New Zealand
- ²⁴ Global Mammal Assessment Program, Department of Biology and Biotechnologies, Sapienza University of Rome, Italy
- ²⁵ Center for Global Wildlife Conservation, State University of New York College of Environmental Science and Forestry, USA
- ²⁶ Univ Montpellier, IRD, IFREMER, CNRS, MARBEC, Montpellier, France
- ²⁷ School of Science, University of Waikato, New Zealand
- ²⁸ Stanford Center for Ocean Solutions, Stanford University, Stanford, CA, USA
- ²⁹ Tufts University, Medford, MA 02155, USA
- ³⁰ University of Sao Paulo, Oceanographic Institute, Fisheries Ecosystems Laboratory (LabPesq), Brazil
- ³¹ IFREMER, Unité halieutique Manche Mer du Nord Ifremer, Boulogne-sur-mer, France
- ³² UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), Cambridge, UK
- ³³ Department of Ecosystem Studies, University of Tokyo, Japan
- ³⁴ Senckenberg Biodiversity and Climate Research Centre (BiK-F), Frankfurt, Germany
- ³⁵ Department of Physical Geography, Goethe-University, Frankfurt, Germany
- ³⁶ Global Biodiversity Information Facility Secretariat, Copenhagen Ø, Denmark
- ³⁷ I.I. Schmalhausen Institute of Zoology of National Academy of Sciences of Ukraine, Kyiv, Ukraine
- ³⁸ U.S. Geological Survey, North Central Climate Adaptation Science Center, Boulder, CO, USA
- ³⁹ Department of Wildlife Biology, Forestry and Forest Products Research Institute (FFPRI), Forest Research and Management Organization, Japan
- ⁴⁰ Natural History Museum of Argentina, Parque Centenario, Argentina
- ⁴¹ Potsdam Institute for Climate Impact Research (PIK), Member of the Leibniz Association, Potsdam, Germany
- ⁴² Institute of Environmental Sciences, Leiden University, Leiden, The Netherlands
- ⁴³ Institute for Global Environmental Strategies (IGES), Kanagawa, Japan
- ⁴⁴ School of Public Policy and Global Affairs, University of British Columbia, Vancouver, Canada
- ⁴⁵ Net Zero and Resilient Farming, Rothamsted Research, Harpenden, UK
- ⁴⁶ School of Natural Sciences, Bangor University, Bangor, UK
- ⁴⁷ CIBIO (Research Centre in Biodiversity and Genetic Resources)–InBIO (Research Network in Biodiversity and Evolutionary Biology), Universidade do Porto, Vairão, Portugal

Abstract

The Nature Futures Framework (NFF) is a heuristic tool for co-creating positive futures for nature and people. It seeks to open up a diversity of futures through mainly three value perspectives on nature – Nature for Nature, Nature for Society, and Nature as Culture. This paper describes how the NFF can be applied in modelling to support decision-making. First, we describe key considerations for the NFF in developing qualitative and quantitative scenarios: i) multiple value perspectives on nature as a state space where pathways improving nature toward a trade-off frontier can be represented, ii) incorporating mutually reinforcing key feedbacks of social-ecological systems, iii) indicators describing the evolution of complex social-ecological systems. We then present three approaches to modelling Nature Futures scenarios in the review, screening, and design phases of policy processes. This paper seeks to facilitate the integration of relational values of nature in models and strengthen modelled linkages across biodiversity, nature’s contributions to people, and quality of life.

Keywords: scenario analysis, biodiversity, conservation, sustainability, values, futures

1. The need for positive scenarios in transformative change

The Global Assessment of Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) found that existing scenarios developed by the broader climate community (e.g., shared socio-economic pathways [SSPs], representative concentration pathways [RCPs]), even in their most sustainable combinations (i.e., SSP1 and RCP2.6), would fail to halt biodiversity loss and continue to deteriorate regulating ecosystem services into the future in many parts of the world (H. M. Pereira *et al.*, 2020). This comes with potentially large socio-economic consequences (Johnson *et al.*, 2020) and inequitable impacts borne by poorer countries (Chaplin-Kramer *et al.*, 2019).

The drivers of biodiversity loss and other environmental degradation are rooted in population growth and inequality (Hamann *et al.*, 2018), unsustainable production and consumption patterns (Hoekstra and Wiedmann, 2014), provision of environmentally harmful subsidies (Dempsey, Martin and Sumaila, 2020), poor governance regimes and limited recognition of the importance of biodiversity conservation (Smith *et al.*, 2003), the strong reliance on fossil fuels (Arneth *et al.*, 2019) and the combined impact of multiple anthropogenic stressors in complex social-ecological systems (Alava *et al.*, 2022), among others. To effectively address these and to increase the willingness to enhance biodiversity conservation policies, we need societal transformations across sectors at all levels concurrently and synergistically (Chan *et al.*, 2020). Furthermore, revitalizing the relationship between people and nature is fundamental in increasing priority for sustainability issues, in particular, but not exclusively, in developed countries (Amel *et al.*, 2017), that have a growing share of responsibility for remote biodiversity and habitat loss from natural resource exploitation (Swartz *et al.*, 2010), international trade (Chaudhary and Kastner, 2016) or degraded ecosystem capacity (Marques *et al.*, 2019). We need changes in norms and beliefs that result in the behavioural change (Kinzig *et al.*, 2013), aided by effective governance (Amano *et al.*, 2018), financial instruments (Waldron *et al.*, 2017), as well as individual champions who inspire collective action (Amel *et al.*, 2017). Most importantly, optimism and empathy can contribute to responsible actions if actors see that they can make a difference (Brown *et al.*, 2019; Knowlton, 2019; Blythe *et al.*, 2021) and when the process engages the imagination of transformative futures (Pereira *et al.*, 2019).

Scenarios that incorporate societal transformation can contribute to reversing negative biodiversity trends and moving towards positive futures (Fischer and Riechers, 2019; Leclère *et al.*, 2020). Drawing on a rich plurality of people's values and preferences on nature is key to an improved decision-making (Pascual *et al.*, 2021; IPBES, 2022b), ensuring equitable sharing of benefits and responsibilities. Since 2017, a new scenarios and modelling framework is being developed under IPBES to reposition biodiversity and nature at the centre of policy and governance at all levels, recognizing their essential role in supporting human well-being and sustainability (Rosa *et al.*, 2017). A series of visioning consultations took place with stakeholders and experts from diverse backgrounds. As a result, the Nature Futures Framework (NFF) emerged to inspire the development of nature and people positive, diverse values-integrated, and multiscale scenarios (L. M. Pereira *et al.*, 2020).

This paper reflects on how the NFF can be applied in modelling Nature Futures scenarios to inform policy, based on results of stakeholder visioning and expert elicitation workshops (see Supplementary Materials for more details). First, we present three key principles of the NFF for developing qualitative and quantitative scenarios and models. We then describe three types of applications for integrating Nature Futures scenarios in policy processes. This paper aims to help enhance the utility of scenarios and modelling in the implementation of multiscale policy frameworks such as the Kunming-Montreal Global Biodiversity Framework (GBF) of the United Nations (UN) Convention on Biological Diversity

(CBD), Paris Agreement of the UN Framework Convention on Climate Change (UNFCCC) and the UN Sustainable Development Goals (SDG) agenda with critical challenges to be overcome (Leadley *et al.*, 2022; Perino *et al.*, 2022).

2. Key considerations for Nature Futures scenarios

This section presents three key considerations that are important in developing qualitative and quantitative scenarios of Nature Futures. These were conceptualized through expert elicitation (PBL, 2019a, 2019b), building on limitations and gaps identified in the IPBES Methodological Assessment on Scenarios and Models (IPBES, 2016) and stakeholder visions on positive futures for nature and people (Lundquist *et al.*, 2017; L. M. Pereira *et al.*, 2020) (see Supplementary Materials, SM hereafter).

2.1 Nature Futures value perspectives and the frontier

Individuals and societies value nature in diverse ways. The NFF attempts to capture these in three main perspectives. The Nature for Nature (NN) perspective appreciates and preserves nature for what it is and does and maps to intrinsic and existence values of biodiversity (e.g., maintaining natural processes and function such as evolution and migration) (Chan *et al.*, 2016). The Nature for Society (NS) perspective focuses on instrumental values as in benefits that nature provides to people (e.g. supporting crop production and climate regulation) (Pascual *et al.*, 2017). Finally, the Nature as Culture (NC) perspective values the relationships that nature and people co-create, not as separate entities but as an indivisible whole (e.g., preserving emblematic species, sacred landscapes, and traditional knowledge) (Himes, 2018). These value perspectives of the Nature Futures Framework are envisaged to broaden and diversify stakeholders' visions for nature and people through exploring, mapping and combining different futures and interventions that can help achieve those visions on gradients such as autonomy of nature, instrumental values and the importance of culture in shaping and being shaped by nature (Figure 1). It is important to note that these three value perspectives are a simplification of a hyperdimensional space representing the multiple and varied perspectives of individuals and communities about nature. One way of thinking about the three perspectives is as a principal component analysis of the hyperdimensional space of nature preferences that captures three main complementary axes.

Descriptive characteristics of the Nature Futures value perspectives

Figure 1. Descriptive characteristics of the Nature Future value perspectives and the space between these perspectives where the values converge. A wide range of interventions can be identified using the Nature Futures Framework, reflecting the local context where the framework is being applied. Most systems and places in the world have a mix of these values and map somewhere inside the triangle of the Nature Futures Framework.

However, the three value perspectives on nature are not mutually exclusive of each other – in fact, they are intricately connected and can reinforce each other (Martín-López, 2021). Keystone species are such an example with their functional role benefiting both nature and people (e.g., top predators play an important function by controlling herbivore populations but incidentally this also reduces damage to crops) (Schmitz *et al.*, 2018; Martin, Chamaillé-Jammes and Waller, 2020). Thus, although we represent the Nature Futures state space of social-ecological systems with three axes as orthogonal for simplicity (Figure 2a), a more precise representation would have these axes as partially overlapping (see SM F Glossary for the definition of ‘state space’). This means an increase in the values along one axis can correspond to an increase along another axis. In some parts of the state space, there may be trade-offs between improvements in different axes, corresponding effectively to a frontier in the state space (Figure 2a) (See SM F Glossary for the definition of ‘frontier’) (Polasky *et al.*, 2008). When the value of a given axis is already very high, further improvements along that axis may only be achievable by decreasing the value along another axis. We do not know the shape of this frontier, but we represent it as a convex

surface because the trade-offs in most instances may not be as strong, and for most of the state space, increases are possible across the three value perspectives.

Figure 2. (a) Nature Futures state space with multiple pathways (blue dotted non-linear paths) to the Frontier (green convex with blue dots) where all three value perspectives improve relative to the present. (b) Nature Futures policy space with example policies for the three nature value perspectives and the overlapping presence of these values illustrated by blue, yellow and orange triangles.

The state of systems can be plotted into a multidimensional state space by evaluating the system on each dimension of the value perspectives (Figure 2a). Conceptually speaking, these perspectives can then be seen as projections representing both the historical pathway of a system to date and future pathways towards desirable endpoints (so-called ‘Nature Futures Frontier’) in this state space (Figure 2a). Typically, desirable Nature Futures correspond to points in the state space where there is an improvement in all three value perspectives into the future relative to the present. We can assess particular actions or policies to see how the system moves towards different points of the state space. To do this, we can score the relative contribution of a given action or policy on the axes representing different value perspectives and map them in a policy space of Nature Futures (Figure 2b) (see SM F Glossary for the definition of ‘policy space’).

An important feature of the NFF is that many interventions can be appropriate and are necessary under more than one perspective. In this sense, many individual interventions and even scenarios (i.e., sets of multiple interventions) representing Nature Futures would map somewhere inside the NFF triangle with positive impacts across the three perspectives. As an illustrative example, there are different categories of protection in protected areas – they can strictly protect nature with limited human use (predominantly representing Nature for Nature), allow active management for sustainable use (Nature for Society), or protect cultural landscapes to maintain the relationship and heritage between communities and their

surrounding environment (Nature as Culture). These land protection and management regimes have the greatest impacts in one of the perspectives but also have positive impacts in the condition of nature in the other perspectives. For instance, strictly protected areas benefit society in the longer-term future by improving regulating services such as improved air and water quality. Similarly, protecting cultural landscapes and ensuring sustainable use of natural resources contribute to conserving many species that are associated with human management of landscapes and seascapes while improving social cohesion and inter-generational equity that can contribute to quality of life (Figure 2b, Figure 4).

Furthermore, one can envision a world where different places of the world are managed exclusively for one of the value perspectives at the more local scale, but at the regional and certainly, at the global scale, all three value perspectives must coexist given the diversity of values and human-nature relationships across the globe. One can also envision futures where all perspectives co-exist in all locations or where there is some spatial segregation of the perspectives, corresponding either to a cloud of points towards the centre of the frontier or dispersing them across all corners of the frontier in the Nature Futures state space (Figure 2a).

2.2 Social-ecological systems with feedbacks

Feedbacks between people and nature are central to the IPBES conceptual framework (Díaz, 2015). Understanding interactions and feedbacks is key to understanding the types of non-linear dynamics that move the system or place towards or away from nature and people positive futures (Rocha *et al.*, 2020). However, only limited social-ecological feedbacks are captured in existing environmental models (Akçakaya *et al.*, 2016; Elsawah *et al.*, 2020; Pereira *et al.*, 2021).

In Nature Futures scenarios, we want to find interventions that lead to improvements in one or more nature value perspectives or even trigger synergies in interventions across the perspectives in social-ecological systems. For instance, securing land ownership and management by indigenous peoples and local communities can maintain habitats to conserve biodiversity (NN), whilst preserving long-standing traditional knowledge and cultural heritage (NC) and ensuring societal benefits from sustainable livelihoods (NS) (Dinerstein *et al.*, 2020). Thus, identifying interventions with a single or multiple nature value perspectives is particularly important for understanding where multiple values are present (O'Connor *et al.*, 2021; Sala *et al.*, 2021) and can reinforce each other.

Each Nature Future value perspective has different feedback dynamics, but feedbacks between conservation interventions and social-ecological systems are not well studied (Miller, Caplow and Leslie, 2012), let alone well represented in existing models. To date, most modelling approaches have adopted Nature for Nature and Nature for Society perspectives (Robinson *et al.*, 2018), but only partially (e.g., the role of pollination in food provision but not the soil). First, the link between biodiversity and ecological functions and ecosystem service provision is not well modelled, though attempts are being made (Weiskopf *et al.*, 2022). Furthermore, many models represent agricultural land conversion in which crop production interacts with demand for it to drive land-use change (Lambin and Meyfroidt, 2011; Stehfest *et al.*, 2019) and, in some cases, changes in production feedback to impact human wellbeing (Chaplin-Kramer *et al.*, 2019). But we lack models representing how some interventions such as land-use change that optimize values of nature in different combinations (e.g., extending protected areas in indigenous land, increasing multifunctional agroforestry) result in changes in ecosystem services and good quality of life, and this may, in turn, affect societal decisions on the processes of future land-use. The Nature for Nature perspective is represented in ecological models, some of which capture ecological feedback processes such as fire dynamics (McLauchlan *et al.*, 2020), but for instance, multiple roles and benefits of keystone species, such as beavers creating wetlands and landscape

heterogeneity by felling trees and blocking water flows, is still missing in estimating their eventual contributions to human wellbeing (Wohl, 2013; Lazar *et al.*, 2015; Stout, Majerova and Neilson, 2017; Willby *et al.*, 2018) (Figure 3).

Dynamics between human and natural systems and Nature Futures values perspectives

Figure 3. A simple diagram with feedback loops represents the dynamics between human and natural systems within and between the systems that reflect Nature Futures' value perspectives.

Feedbacks that are important for Nature as Culture perspective are the least understood and modelled. For example, cultural keystone species, such as Western Red Cedar in Coastal British Columbia, connect a web of social-ecological feedbacks in which cultural practices are linked to spiritual traditions and a long-term outlook of the community's livelihood and heritage (Garibaldi and Turner, 2004). However, we do not have models that incorporate social-ecological feedbacks around cultural keystone species. There are initiatives that enhance a structured understanding of the social-ecological feedbacks (Lauerburg *et al.*, 2020; Rocha *et al.*, 2020) with participatory scenarios applied at one system's scale (Sitas *et al.*, 2019). In general, however, coupled social-ecological modelling is still in its infancy and requires further development, particularly in representing consequential cross-scale interactions (Leadley *et al.*, 2014; Cheung *et al.*, 2016; Keys *et al.*, 2019; Elsayah *et al.*, 2020)

2.3 Indicators of knowledge and data as multiple evidence bases

Going from the visions and narratives of Nature Futures scenarios to policy support, indicators derived from models, data, and other knowledge systems become an integral part of the evidence bases for decision-making (Tengo *et al.*, 2014). Indicators can describe and measure the state, trends, and magnitudes of relationships between different components of key social-ecological systems, and help identify models, variables and data required to generate evidence (Gutzler *et al.*, 2015; Guerra, 2019). Methods such as mental mapping, decision tree and multi-criteria analyses can be used to select or derive key indicators. To be inclusive of and to explicit diverse value perspectives on nature, indicators are ideally co-determined and co-developed with stakeholders and users of the information (van Oudenhoven *et al.*, 2018; Miola, 2019).

Using the IPBES conceptual framework and the Nature Futures Framework, interventions can be explored and selected on a range of direct (anthropogenic, natural) and indirect (institution, governance,

anthropogenic assets) drivers for the assessment of their potential impact on goals set on nature, nature's contributions to people and quality of life. As illustrated in Table 3 and Figure 4, interventions and goals can be cross-cutting, (e.g., supporting community learning facilities that enhance public awareness on conservation and sustainability issues, preventing species extinction and ecosystems degradation for intergenerational equity) or they can have a "home" in one of the value perspectives, as demonstrated in the policy space of Figure 2b (e.g., different types of land and ocean protection and management). For life satisfaction as an illustrative example goal on quality of life, NN can be measured by the enjoyment of experiencing nature and knowing that other species are protected, NS from using quality goods from nature and knowing that they are equitably shared or NC from preserving nature-based cultural heritage and thereby maintaining people's relationship with nature and social cohesion (Table 1).

As illustrated, indicators representing diverse values, roles and benefits of nature can provide richer insights and evidence for assessing and introducing changes in social-ecological systems that can lead to more integrated and comprehensive analyses, optimization, and prioritization of conservation and sustainability strategies for multiscale policy frameworks such as the CBD GBF, Paris Agreement, and UN SDGs (O'Connor *et al.*, 2021; Sala *et al.*, 2021; Soto-Navarro *et al.*, 2021; CBD Secretariat, 2022).

315 **Table 1.** Illustrative features of the Nature Future scenarios perspectives with example indicators associated with those features. The components of the IPBES conceptual
316 framework are used to identify the interventions and goals (rows) across the three Nature Futures value perspectives and those that can be cross-cutting (columns). Existing indicators
317 are identified from the CBD Global Biodiversity Framework (CBD Secretariat, 2022), UN SDGs (UNDESA, 2021; UNSTATS, 2022), and Indigenous Navigator (Indigenous
318 Navigator, 2023) and the remaining indicators are aspirational (gaps) without the global coverage in data.

Framework components	Cross-cutting	Nature for Nature	Nature for Society	Nature as Culture
Interventions on indirect drivers - Institutions and governance	Promoting national and international systems and cooperation on biodiversity issues (e.g., <i>CBD Goal D. Funding on conservation and sustainable use of biodiversity and ecosystems by international and domestic public and private sources</i>)	Giving legal rights to nature and adequate management capacity to protect nature (e.g., <i>% of countries or municipalities that have assigned rights to nature in their constitutions</i>)	Developing environmentally friendly infrastructure for human settlement (e.g., <i>SDG 7.b.1 Installed renewable energy-generating capacity in developing countries (in watts per capita)</i>)	Including indigenous and local knowledge of nature in education curriculum (e.g., <i>% education facilities that have curriculum on indigenous and local knowledge of nature</i>)
	Implementing agro-environmental measures not perverse to nature conservation and human wellbeing (e.g., <i>CBD Target 18. indicator/index measuring the overall impact of agro-environmental measures on nature and people</i>)	Implementing agro-environmental measures targeting high production on most fertile lands, avoiding biodiverse areas, to spare space for nature (e.g., <i>% agro-environmental measures allocated to fertile lands and their productivity level</i>)	Implementing agro-environmental measures targeting maximum co-production of ecosystem services (e.g., <i>% agro-environmental measures allocated to maximize co-production of ecosystem services</i>)	Implementing agro-environmental measures targeting environmentally friendly smallholder production in cultural landscapes for local consumption (e.g., <i>% agro-environmental measures allocated to smallholder production in the cultural landscape for local consumption</i>)
- Anthropogenic assets	Community learning facilities that enhance public awareness and activities on conservation and sustainability issues (e.g., <i>Number of public events on conservation and sustainability topics</i>)	Creating protection, management and education facilities for wildlife watching (e.g., <i>Number of wildlife-watching facilities by protection level, management type, and educational programs</i>)	Engaging the private sector to deploy nature-based solutions that benefit both nature and people (e.g., <i>Amount of investment by private firms in deploying nature-based solutions</i>)	Establishing community associations for supporting local production and consumption and fair trade (e.g., <i>INI Art 20. Trends in consumption of diverse locally-produced food</i>)
Interventions on direct drivers - Anthropogenic and natural	Designating different types of protected areas (e.g., <i>CBD Target 3. % area covered by protected areas by type – marine, coastal, terrestrial, inland water</i>)	Strict protection areas and rewilding of abandoned and degraded land to improve biodiversity, e.g., introduction of large herbivores (e.g., <i>strict protection areas,</i>	Sustainable use protected areas and nature-based solutions to mitigate climate impact, e.g., afforestation, urban parks, renewable energy like solar and wind power	Cultural landscape protection and traditional management of natural resources, e.g., other effective area-based conservation measures (OECMs) where wild crop relatives grow

Framework components	Cross-cutting	Nature for Nature	Nature for Society	Nature as Culture
		% of total land being rewilded, reforested and restored)	(e.g., % contribution of NBS to climate change mitigation by type)	(e.g., % of the total land with wild crop relatives by management type)
Goals on nature - Biodiversity and ecosystems	Preventing species from extinction (e.g., CBD Goal A. Species Habitat Index, number of species prevented from extinction, extent of natural ecosystems)	Protecting species important for biodiversity, ecological processes and ecosystem functions (e.g., Protection status of species important for ecosystems)	Protecting species and ecosystems important for material and regulating services (e.g., Protection status of species important for providing ecosystem services)	Protecting species and landscape important for local communities and cultural heritage (e.g., Protection status of species important for cultural reasons)
Goals on nature's contributions to people - Ecosystem services	Preventing degradation of ecosystem functions and services (e.g., CBD Goal B. water regulation) Equitable sharing of benefits from nature (e.g., Distribution, stocks and flows of ecosystem services by type across regions)	Advancing remote and longer-term benefits from conserving nature (e.g., % change in carbon capture and sequestration from nature by type – forest, oceans, etc.)	Provision of immediate material and regulating services from nature (e.g., % population who benefited from pollination-based crop consumption, % population who benefited from water regulation/nitrogen retention)	Provision of benefits from nature that communities appreciate for their relational connections (e.g., # of cultural keystone species, % population that preserved intergenerational cultural heritage from nature)
Goals on quality of life	Life satisfaction from basic needs met (e.g., food, water, security) (e.g., SDG 2.1.1 Prevalence of undernourishment, SDG 6.1.1 % of population using safely managed drinking water services, % population that were protected from nature-based coastal risk reduction)	Life satisfaction from the enjoyment of experiencing nature and knowing that other species are being protected (e.g., % population with life satisfaction from experiencing nature, % population with access to green space within X miles of their residence, % population donating their time or money to environmental causes)	Life satisfaction from various types of quality goods and services from nature and knowing that they are equitably shared (e.g., % population with life satisfaction from goods and services from nature, % population that believe nature's benefits should be equally distributed)	Life satisfaction from preserving nature-based cultural heritage and intergenerational social cohesion (e.g., INI Art 26(2). Possibility to perform traditional occupations (such as pastoralism, hunting/gathering, shifting cultivation, fishing) without restriction as a proxy)

*Sources (for existing indicators): CBD: Convention on Biological Diversity, SDG: Sustainable Development Goals, INI: Indigenous Navigator Indicator

*Note that the assignment of specific interventions to specific value perspectives does not mean that they cannot be used under other value perspectives. It only indicates that they are particularly relevant from that value perspective. The indicators in this table are provided only as examples to illustrate a selection of indicators for Nature Future scenarios.

3. Modelling Nature Futures scenarios to inform policy

This section presents three application approaches to modelling Nature Futures scenarios to inform policy processes: policy review, policy screening and policy design or agenda-setting, as laid out in the IPBES methodological assessment on scenarios and models (Table 1) (IPBES, 2016).

Table 2. Modelling application of Nature Futures scenarios in policy processes

	Application 1. Policy review (<i>ex-post</i>)	Application 2. Policy screening (<i>ex-ante</i>)	Application 3. Policy design or agenda setting (<i>ex-ante</i>)
Objectives	Evaluates the effects of implemented policies retrospectively in time	Assesses particular policy and management options, often for the short term	Identifies broader goals for policy-making over longer time scales
Policy question (examples)	What were the trends of biodiversity and ecosystem services in the past? What happened in places where particular policies were implemented (e.g., different types of protected areas and their impact)?	What will be the consequences for biodiversity, ecosystem services and quality of life of different policy interventions affecting, particularly, direct drivers (e.g., location and types of protected areas)?	What societal transformations need to occur to achieve long-term visions for people and nature? How do changes in nature's contributions to people affect societal decisions (e.g., how do benefits of protected areas inform societal decisions on land/sea spatial planning)?
Policy tool (examples)	CBD National Reports	CBD Local and National Biodiversity Strategy and Action Plans	CBD Post-2020 Global Biodiversity Framework
Modelling approaches (examples)	Emphasizes past observations. Counterfactuals can be examined with techniques such as statistical matching or before-after control impact	Models of impacts of direct drivers on biodiversity and ecosystem services models	Integrated assessment models at large scales, dynamic social-ecological models at smaller scales
Key modelling challenges	Integrating time series monitoring in biodiversity and ecosystem services, impact models of diverse drivers	Connecting biodiversity, ecosystem functions and services, and quality of life, incorporating a broader set of drivers in impact models	Long-term social-ecological feedbacks at large scales, and incorporation of tipping points/regime shift

3.1 Objectives and methods for modelling application

The Nature Futures Framework can be used in exploring a much broader array of interventions, compared to previous environmental scenarios, integrating diverse values, roles and benefits of nature. Thus, it can be used to inform multiscale policy frameworks at local, national and global scales (e.g., CBD National Biodiversity Strategy and Action Plans, CBD National Reports, CBD Post-2020 Global Biodiversity Framework), helping to identify interventions, set targets, and monitor progress towards the goals (Baylis *et al.*, 2016; Strassburg *et al.*, 2020). The NFF can be applied retrospectively to evaluate the performance of implemented policies (policy review) (Kim, HyeJin, 2022), assess potential consequences of a particular policy (policy screening) (O'Connor *et al.*, 2021) or identify broader goals for policy agenda (policy design and agenda-setting) (Sala *et al.*, 2021) (Table 2).

In policy review, evidence synthesis can use methods such as systematic review (Pullin and Stewart, 2006; Bowler *et al.*, 2010) and meta-analyses (Konno and Pullin, 2020) or impact assessment employing econometric and statistical techniques such as matching (Schleicher *et al.*, 2020; Ribas, Pressey and Bini, 2021) and before-after control impact (Smokorowski and Randall, 2017; Ferraro, Sanchirico and Smith, 2019). Counterfactual analysis of the impact of direct drivers on biodiversity and nature's contributions to people can inform where and how biodiversity has been changing due to implemented policies (e.g., protected areas with different priorities on nature, people and culture) compared to those areas where such measures did not take place (Jellesmark *et al.*, 2021; Sze *et al.*, 2021). Furthermore, impact models of direct drivers on biodiversity (Balvanera, Patricia *et al.*, 2019) can fill spatial and temporal gaps in historical data that are then key to assessing impacts on ecosystem services (Fernández *et al.*, 2020).

In policy screening, models can predict the consequences of different policy interventions, particularly direct drivers (e.g., changes in land use or direct exploitation, such as fishing, or location and types of protected areas), reflecting different nature value perspectives on biodiversity, ecosystem services, and quality of life (Fulton *et al.*, 2015; O'Connor *et al.*, 2021; Sala *et al.*, 2021). For these relatively short-term analyses (e.g., one decade), modelling a broader range of direct drivers (e.g., control of invasive species, pollution, resource exploitation) (Kettenring and Adams, 2011; Ning *et al.*, 2021) is more important than incorporating full dynamics of indirect drivers (e.g., demographic change, GDP, institutional effectiveness), which may not be necessary or feasible (Akçakaya *et al.*, 2016; Brotons *et al.*, 2016).

In policy design and agenda-setting, a broader set of social-ecological feedbacks can be modelled to identify multiple societal transformation pathways to achieving long-term visions, ensuring that the impact of interventions on nature on people inform future decisions (e.g., how benefits of protected areas inform societal decisions on spatial planning, land tenure or subsidy schemes) (Sze *et al.*, 2021; Alava *et al.*, 2022; Pacheco and Meyer, 2022). Here, modelling the key feedbacks in social-ecological systems with interventions on indirect drivers is essential in developing scenarios with robust strategies (Akçakaya *et al.*, 2016; Brotons *et al.*, 2016; Keys *et al.*, 2019; PBL, 2019b, 2019a) (Figure 4).

3.2 Scenario analysis in state space and policy space

For scenario analyses to support policy using the NFF, a single policy can be scored and mapped in the Nature Futures policy space to assess how the system did and will evolve along the three perspectives (Figure 2b). Another example is to look at how different management options play out over time, given, for example, the impact of climate change (Palacios-Abrantes *et al.*, 2022; Parmesan, C. *et al.*, 2022) or a change in fishery regulation (Halouani *et al.*, 2016). Although most policies will impact the system across the three value perspectives, some policies may particularly favour one perspective over the others (see Figure 1, Table 1). When it is done well in consultation and discussion with stakeholders, assigning equitable interventions to different nature value perspectives allows us to evaluate the consequences of different preferences and priorities inherent in decision options (Pascoe, Plagányi and Dichmont, 2017).

Furthermore, a combination of policies can be tested through models and indicators and analyze how the key levers/interventions can progress the system along the three axes in the state space and eventually towards the Nature Futures Frontier (Figure 2a) (Palacios-Abrantes *et al.*, 2022; Haga *et al.*, 2023). For example, marine protected areas (representing NN when it excludes people from conservation areas) (Brown *et al.*, 2001; Sala and Giakoumi, 2018), other effective area based management (emphasising NC with traditional management practices) (Schmidt and Peterson, 2009;

Nemogá, Appasamy and Romanow, 2022) and sustainable harvest from fisheries (NS with direct instrumental benefit from sustainable management) (Asche *et al.*, 2018; Hilborn *et al.*, 2021) can be assessed in the policy space (Figure 2b) or together with other sustainability and conservation interventions (e.g., banning plastics and oil drilling, restoration of coral reefs) in an integrated way in the state space (Figure 2a, Figure 4) (see Section 3.1). A modelling framework can be developed (as shown in Figure 4) to assess the state and changes of the key social-ecological system in the Nature Futures scenarios (see Section 3.2). Further, a range of variables and indicators can be selected to quantify Nature Futures scenarios in the state space (as illustrated in Table 1), which can be generated from data or models (see Section 3.3).

This means that to represent the evolution of the system quantitatively in a three-dimensional state space, some projections of indicators with a single score per axis are needed on the three Nature Futures axes (NN, NS, NC) (Figure 2a). There can be indicators commonly used across all Nature Future scenarios (so called ‘cross-cutting’ or ‘common’ indicators) and indicators that are specific to each of the three value perspectives (so called ‘specific’ indicators) (see Table 1 for examples). Then the overall score for each of the three nature value perspectives can be calculated by deriving an index across all indicators associated with each scenario. To generate common or specific indicators, an individual to a suite of models is needed to assess the impacts of drivers and associated interventions on nature, nature’s contributions to people and eventually the quality of life, retrospectively or prospectively (Figure 4).

Developing Nature Futures modelling framework on social-ecological systems dynamics

Figure 4. An illustrative modelling framework on the sustainable sea and land use using components of the IPBES conceptual framework with interventions on indirect and direct drivers (left panel) and goals on nature, nature's contributions to people and quality of life (right panel). The Nature Futures scenarios can combine different degrees of nature values through interventions (input) to assess their consequences on nature and people (output). A few illustrative interventions on direct drivers are rewilding abandoned land (primarily for Nature for Nature), traditional forest and fishery management practices (primarily for Nature as Culture) and nature-based solution such as city's green infrastructure (for Nature for Society) as value reflected interventions into modelling, further supported by indirect drivers including governance, implementation subsidy measures and education. The state of nature, nature's contributions to people, and quality of life are ideally measured using multiple indicators that represent diverse roles, values and benefits of nature. The Nature Futures scenarios emphasize identifying synergistic interventions with co-benefits that can reinforce key social-ecological feedbacks onto the pathways to the Nature Futures Frontier.

3.3 Key remaining challenges to modelling Nature Futures scenarios

Most modelling approaches have not incorporated multiple values of nature or only do so in a limited fashion (Brown, Seo and Rounsevell, 2019). This is particularly true for the relational values of nature. As illustrated, integrating diverse value perspectives in modelling the Nature Futures scenarios is essential for a more comprehensive assessment of the impact of societal decisions on nature and people. (Table 1, Figure 4).

Time-series monitoring data in impact models of direct drivers on biodiversity and ecosystem services remains a key challenge (Rosa *et al.*, 2020). Most existing biodiversity models use space for time replacement in the calibration of models (Walters and Scholes, 2017). This is relevant for the retrospective policy evaluation where time-series data are prerequisites for impact evaluation or evidence synthesis (Rodrigues and Cazalis, 2020). Furthermore, historical observation data and empirical evidence are fundamental for developing rigorous models for predicting the future (Urban *et al.*, 2022).

An increasing suite of models, variables and indicators are being made available for the assessment of biodiversity and nature's contributions to people (Tittensor *et al.*, 2017; Kim *et al.*, 2018; Chaplin-Kramer *et al.*, 2020; Willcock *et al.*, 2020). However, a broader range of drivers and interventions, in particular of those with positive impacts on nature and people, needs to be represented in models for screening and identifying policy interventions that are critically called for in Nature Futures scenarios (Leclere *et al.*, 2018; IPBES, 2019; PBL, 2019b; CBD Secretariat, 2022).

New models are in development that incorporates social-ecological feedbacks reflecting the impacts of biodiversity and ecosystem services provision on the economy and vice versa (Banerjee *et al.*, 2020; Johnson *et al.*, 2020). However, scenarios and models need to fully consider cross-scale interactions (e.g., connections between local, regional, and global dynamics and outcomes), social-ecological feedbacks, and tipping points/regime shifts if they are to inform policy effectively (Keys *et al.*, 2019; PBL, 2019a; Rocha *et al.*, 2020).

The Shared Socioeconomic Pathways (SSP) and Representative Concentration Pathways (RCP) scenario frameworks have been used extensively in biodiversity and climate research (IPCC, 2015; IPBES, 2019). The biodiversity and ecosystem services model intercomparison carried out for the IPBES Global Assessment revealed that all SSP/RCP scenarios except for the most sustainable combination SSP1/RCP2.6 would result in biodiversity loss and ecosystem degradation across the globe, with increasing climate impact in the coming decades (IPBES, 2019; H. M. Pereira *et al.*, 2020). Given that the RCP/SSP scenarios have been developed for the IPCC process and thus have a strong climate change and mitigation focus, their adaptation to the NFF will be challenging.

The NFF may be only relevant as extensions of the SSP1, or the world could start from different SSPs and the NFF is used to identify diverse pathways onto positive future (IPBES, 2021, 2022a). The recent 6th IPCC Assessment Reports highlight some of the new scenario approaches, including the Climate Resilience Development Pathways and Illustrative Mitigation Pathways, which, together with the Nature Futures Framework, can help co-develop new scenarios for climate and biodiversity (IPCC 2022a, IPCC 2022b). Still, a continued joint effort is needed in developing future scenarios with interventions on relevant drivers reflecting diverse values of nature and worldview are tested in conserving biodiversity, mitigating climate impact, and ensuring human well-being, justice and intergenerational equity.

Furthermore, uncertainties need to be explored in Nature Futures scenarios, including the models and their structures, methodologies, assumptions, parameters, data and indicators, and from epistemological and ontological differences across sectors, disciplines and cultures (Regan, Colyvan and Burgman, 2002; Dunford, Harrison and Rounsevell, 2015, p. 201; Rounsevell *et al.*, 2021). Common definitions, modelling protocols, standard data format, and further guidance on the application of the NFF will support more consistent scenarios and modelling practices (Pereira *et al.*, 2013; Wilkinson *et al.*, 2016; Urban *et al.*, 2022). Importantly, uncertainties associated with Nature Futures scenarios and modelling should be communicated clearly and transparently to the end users (IPBES, 2016).

4. Moving towards Nature Futures

To date, scenarios and models in environmental assessments have tended to focus on representing human impacts on ecosystems and lacked positive futures for nature and people (IPBES, 2016; Rosa *et al.*, 2017; Pereira *et al.*, 2021). Scenarios and models can integrate a broad set of the social-ecological systems and key feedbacks that are of relevance and importance to biodiversity conservation, climate mitigation and human wellbeing (L. M. Pereira *et al.*, 2020). To achieve this, the existing models on biodiversity, ecosystem services need to be mapped and coupled with models on human systems and norms to develop comprehensive frameworks that integrate potential key feedbacks across them (Arneth, Brown and Rounsevell, 2014), improving the representation of globally connected social-ecological systems that exhibit cross-scale interactions (Leadley *et al.*, 2014; Keys *et al.*, 2019). Furthermore, relational values of nature need to be reflected better in the models and indicators, notably improved capacity in modelling how environmental changes alter human behaviour, institutions, and culture and vice versa (Elsawah *et al.*, 2020; O'Neill *et al.*, 2020).

Model algorithms developed based on observed data are crucial to projecting changes into the future (Mouquet *et al.*, 2015; Urban *et al.*, 2016), enhancing the rigor and credibility of models. We can use a wide range of observation data and correlations based on observed trends in drivers to forecast responses of biodiversity and ecosystems under different policy interventions (Petchey *et al.*, 2015). High-resolution remote-sensing and other observational evidence (“big data”), jointly with advanced machine learning technologies and cloud-based computing (Pereira *et al.*, 2013; Willcock *et al.*, 2018; Fernandez, In review), can contribute significantly to increasing the predictive power of changes in biodiversity and nature’s contributions to people (Willcock *et al.*, 2020; Urban *et al.*, 2022). Making Nature Futures scenarios truly nature and people positive thus presents a critical challenge to broader research communities to shift the conventional impact modelling of negative anthropogenic drivers to positive anthropogenic drivers (e.g., biodiversity and people’s positive contributions to nature) on nature and people in a full circle.

As elaborated in this paper, the NFF aims to support transformative change towards sustainable futures by placing human-nature relationships at the centre. It bridges knowledge systems and communities of practices through continuous dialogue, creating a culture of stakeholder-driven scenario development and their co-implementation while maintaining minimum consistency and comparability (Lundquist *et al.*, 2017; Rosa *et al.*, 2017). In the coming years, we expect that the Nature Futures approach will enable scientific and broader stakeholder communities to identify policy and management interventions that reflect diverse ways people can value nature more than we have until now. To achieve this, a participatory approach is being promoted to engage stakeholders in developing narratives, engineering models and building evidence bases for solutions to conservation and sustainability issues (PBL, 2019a, 2019b; L. M. Pereira *et al.*, 2020). This inclusive approach is meant to ensure that the information generated from Nature Future scenarios is relevant and is used by the stakeholders to initiate and amplify

necessary societal transformations. Addressing interlinkages, co-benefits and trade-offs between sectors, such as food, biodiversity, water and energy with so-called nexus approaches, will be vital to finding pathways towards achieving multiple societal goals (Liu *et al.*, 2018; Singh *et al.*, 2018). The Nature Futures is also expected to contribute to the ongoing assessments of IPBES on “transformative change” and “nexus”, which were initiated at the eighth IPBES Plenary session in June 2021.

The ambition of Nature Futures is to help expand the integration of nature in policy-making across sectors and better link the efforts of scientists and knowledge holders to values and associated decisions for nature and people. In an era where combined global environmental changes are at play, marine, terrestrial, and freshwater biodiversity is imperilled. The spread of COVID-19 has transformed intricately coupled nature and human systems, pressing new norms on all societies, and bringing a sense of extreme urgency to build back better and greener. The Nature Future Framework presented in this paper is expected to stimulate that development through scenarios and models that can inform the realization of multiscale policy frameworks such as the UN CBD Kunming-Montreal Global Biodiversity Framework, UNFCCC Paris Agreement, UN Sustainable Development Agenda, and the latest UN Ocean Treaty, thereby bringing the world onto the pathways towards more ecological, liveable, and just futures.

References

- Akçakaya, H.R. *et al.* (2016) ‘Chapter 8 Improving the rigor and usefulness of scenarios and models through ongoing evaluation and refinement’, in *The methodological assessment report on scenarios and models of biodiversity and ecosystem services*. Bonn, Germany: IPBES.
- Alava, J.J. *et al.* (2022) ‘Multiple anthropogenic stressors in the Galápagos Islands’ complex social–ecological system: Interactions of marine pollution, fishing pressure, and climate change with management recommendations’, *Integrated Environmental Assessment and Management*, p. *ieam.4661*. Available at: <https://doi.org/10.1002/ieam.4661>.
- Amano, T. *et al.* (2018) ‘Successful conservation of global waterbird populations depends on effective governance’, *Nature*, 553(7687), pp. 199–202. Available at: <https://doi.org/10.1038/nature25139>.
- Amel, E. *et al.* (2017) ‘Beyond the roots of human inaction: Fostering collective effort toward ecosystem conservation’, p. 6.
- Arneth, A. *et al.* (2019) ‘Chapter 1: Framing and context’, in *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmot.
- Arneth, A., Brown, C. and Rounsevell, M.D.A. (2014) ‘Global models of human decision-making for land-based mitigation and adaptation assessment’, *Nature Climate Change*, 4(7), pp. 550–557. Available at: <https://doi.org/10.1038/nclimate2250>.
- Asche, F. *et al.* (2018) ‘Three pillars of sustainability in fisheries’, *Proceedings of the National Academy of Sciences*, 115(44), pp. 11221–11225. Available at: <https://doi.org/10.1073/pnas.1807677115>.
- Balvanera, Patricia *et al.* (2019) *Chapter 2.1 Status and Trends –Drivers of Change*. Zenodo. Available at: <https://doi.org/10.5281/ZENODO.3831881>.
- Banerjee, O. *et al.* (2020) ‘Global socio-economic impacts of changes in natural capital and ecosystem services: State of play and new modeling approaches’, *Ecosystem Services*, 46, p. 101202. Available at: <https://doi.org/10.1016/j.ecoser.2020.101202>.
- Baylis, K. *et al.* (2016) ‘Mainstreaming Impact Evaluation in Nature Conservation: Mainstreaming impact evaluation’, *Conservation Letters*, 9(1), pp. 58–64. Available at: <https://doi.org/10.1111/conl.12180>.
- Blythe, J. *et al.* (2021) ‘Fostering ocean empathy through future scenarios’, *People and Nature*, p. *pan3.10253*. Available at: <https://doi.org/10.1002/pan3.10253>.
- Bowler, D.E. *et al.* (2010) ‘A systematic review of evidence for the added benefits to health of exposure to natural environments’, *BMC Public Health*, 10(1), p. 456. Available at: <https://doi.org/10.1186/1471-2458-10-456>.
- Brotons, L. *et al.* (2016) ‘Chapter 4 Modelling impacts of drivers on biodiversity and ecosystems’, in *The methodological assessment report on scenarios and models of biodiversity and ecosystem services*. Bonn, Germany: IPBES.
- Brown, C., Seo, B. and Rounsevell, M. (2019) ‘Societal breakdown as an emergent property of large-scale behavioural models of land use change’, *Earth System Dynamics*, 10(4), pp. 809–845. Available at: <https://doi.org/10.5194/esd-10-809-2019>.

- Brown, K. *et al.* (2001) 'Trade-off analysis for marine protected area management', *Ecological Economics*, 37(3), pp. 417–434. Available at: [https://doi.org/10.1016/S0921-8009\(00\)00293-7](https://doi.org/10.1016/S0921-8009(00)00293-7).
- Brown, K. *et al.* (2019) 'Empathy, place and identity interactions for sustainability', *Global Environmental Change*, 56, pp. 11–17. Available at: <https://doi.org/10.1016/j.gloenvcha.2019.03.003>.
- CBD Secretariat (2022) 'Decision adopted by the Conference of the Parties to the Convention on Biological Diversity 15/4. Kunming-Montreal Global Biodiversity Framework'. Available at: <https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf>.
- Chan, K.M.A. *et al.* (2016) 'Opinion: Why protect nature? Rethinking values and the environment', *Proceedings of the National Academy of Sciences*, 113(6), pp. 1462–1465. Available at: <https://doi.org/10.1073/pnas.1525002113>.
- Chan, K.M.A. *et al.* (2020) 'Levers and leverage points for pathways to sustainability', *People and Nature*. Edited by P. Bridgewater, 2(3), pp. 693–717. Available at: <https://doi.org/10.1002/pan3.10124>.
- Chaplin-Kramer, R. *et al.* (2019) 'Global modeling of nature's contributions to people', *Science*, 366(6462), pp. 255–258. Available at: <https://doi.org/10.1126/science.aaw3372>.
- Chaplin-Kramer, R. *et al.* (2020) *Global critical natural assets*. preprint. Ecology. Available at: <https://doi.org/10.1101/2020.11.08.361014>.
- Chaudhary, A. and Kastner, T. (2016) 'Land use biodiversity impacts embodied in international food trade', *Global Environmental Change*, 38, pp. 195–204. Available at: <https://doi.org/10.1016/j.gloenvcha.2016.03.013>.
- Cheung, W.W.L. *et al.* (2016) 'Chapter 6. Linking and harmonising scenarios and models across scale and domains', in *The methodological assessment report on scenarios and models of biodiversity and ecosystem services*. Bonn, Germany: IPBES.
- Dempsey, J., Martin, T.G. and Sumaila, U.R. (2020) 'Subsidizing extinction?', *Conservation Letters*, 13(1). Available at: <https://doi.org/10.1111/conl.12705>.
- Díaz, S. (2015) 'The IPBES Conceptual Framework — connecting nature and people', *Current Opinion in Environmental Sustainability*, p. 16.
- Dinerstein, E. *et al.* (2020) 'A "Global Safety Net" to reverse biodiversity loss and stabilize Earth's climate', *Science Advances*, 6(36), p. eabb2824. Available at: <https://doi.org/10.1126/sciadv.abb2824>.
- Dunford, R., Harrison, P.A. and Rounsevell, M.D.A. (2015) 'Exploring scenario and model uncertainty in cross-sectoral integrated assessment approaches to climate change impacts', *Climatic Change*, 132(3), pp. 417–432. Available at: <https://doi.org/10.1007/s10584-014-1211-3>.
- Elsawah, S. *et al.* (2020) 'Eight grand challenges in socio-environmental systems modeling', *Socio-Environmental Systems Modelling*, 2, p. 16226. Available at: <https://doi.org/10.18174/sesmo.2020a16226>.
- Fernández, N. *et al.* (2020) 'Essential Biodiversity Variables: Integrating In-Situ Observations and Remote Sensing Through Modeling', in J. Cavender-Bares, J.A. Gamon, and P.A. Townsend (eds) *Remote Sensing of Plant Biodiversity*. Cham: Springer International Publishing, pp. 485–501. Available at: https://doi.org/10.1007/978-3-030-33157-3_18.
- Fernandez, N. (In review) 'A unifying framework for Essential Biodiversity Variables'.

Ferraro, P.J., Sanchirico, J.N. and Smith, M.D. (2019) 'Causal inference in coupled human and natural systems', *Proceedings of the National Academy of Sciences*, 116(12), pp. 5311–5318. Available at: <https://doi.org/10.1073/pnas.1805563115>.

Fischer, J. and Riechers, M. (2019) 'A leverage points perspective on sustainability', *People and Nature*, 1(1), pp. 115–120. Available at: <https://doi.org/10.1002/pan3.13>.

Fulton, E.A. *et al.* (2015) 'Modelling marine protected areas: insights and hurdles', *Philosophical Transactions of the Royal Society B: Biological Sciences*, 370(1681), p. 20140278. Available at: <https://doi.org/10.1098/rstb.2014.0278>.

Garibaldi, A. and Turner, N. (2004) 'Cultural keystone species: Implications for ecological conservation and restoration', *Ecology and Society*, 9(3). Available at: <https://doi.org/10.5751/ES-00669-090301>.

Guerra, C.A. (2019) 'Finding the essential: Improving conservation monitoring across scales', *Global Ecology and Conservation*, p. 7.

Gutzler, C. *et al.* (2015) 'Agricultural land use changes – a scenario-based sustainability impact assessment for Brandenburg, Germany', *Ecological Indicators*, 48, pp. 505–517. Available at: <https://doi.org/10.1016/j.ecolind.2014.09.004>.

Haga, C. *et al.* (2023) 'Modeling desirable futures at local scale by combining the nature futures framework and multi-objective optimization', *Sustainability Science* [Preprint]. Available at: <https://doi.org/10.1007/s11625-023-01301-8>.

Halouani, G. *et al.* (2016) 'A spatio-temporal ecosystem model to simulate fishing management plans: A case of study in the Gulf of Gabes (Tunisia)', *Marine Policy*, 69, pp. 62–72. Available at: <https://doi.org/10.1016/j.marpol.2016.04.002>.

Hamann, M. *et al.* (2018) 'Inequality and the Biosphere', *Annual Review of Environment and Resources*, 43(1), pp. 61–83. Available at: <https://doi.org/10.1146/annurev-enviro-102017-025949>.

Hilborn, R. *et al.* (2021) 'The trade-off between biodiversity and sustainable fish harvest with area-based management', *ICES Journal of Marine Science*. Edited by E. Anderson, 78(6), pp. 2271–2279. Available at: <https://doi.org/10.1093/icesjms/fsaa139>.

Himes, A. (2018) 'Relational values: the key to pluralistic valuation of ecosystem services', *Current Opinion in Environmental Sustainability*, p. 7.

Hoekstra, A.Y. and Wiedmann, T.O. (2014) 'Humanity's unsustainable environmental footprint', *Science*, 344(6188), pp. 1114–1117. Available at: <https://doi.org/10.1126/science.1248365>.

Indigenous Navigator (2023) 'INDICATORS FOR MONITORING THE UN DECLARATION ON THE RIGHTS OF INDIGENOUS PEOPLES'. Indigenous Navigator. Available at: https://indigenousnavigator.org/files/media/document/Navigator_UNDRIPIndicators.pdf.

IPBES (2016) *The methodological assessment report on scenarios and models of biodiversity and ecosystem services*. Intergovernmental Platform on Biodiversity and Ecosystem Services.

IPBES (2019) *IPBES Global Assessment on Biodiversity and Ecosystem Services*.

IPBES (2021) *IPBES workshop on modelling Nature Futures scenarios Task force on scenarios and models under the 2030 IPBES rolling work programme*. IPBES/TF/SCN/WSP/2021/1/6. Bonn, Germany: Intergovernmental Platform on Biodiversity and Ecosystem Services, p. 35. Available at: <https://www.ipbes.net/events/task-force-scenarios-and-models-modellers-workshop>.

IPBES (2022a) *IPBES 2nd workshop on modelling Nature Futures scenarios task force on scenarios and models under the 2030 IPBES rolling work programme*. IPBES/TF/SCN/WSP/2022/1/5. Bonn, Germany: Intergovernmental Platform on Biodiversity and Ecosystem Services, p. 22. Available at: <https://www.ipbes.net/events/second-ipbes-workshop-modelling-nature-future-scenarios>.

IPBES (2022b) *Methodological assessment of the diverse values and valuation of nature of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Zenodo. Available at: <https://doi.org/10.5281/ZENODO.6522522>.

IPCC (2015) *Climate Change 2014: Impacts, Adaptation and Vulnerability, Volume 1, Global and Sectoral Aspects Working Group II Contribution to the IPCC Fifth Assessment Report*. Cambridge: Cambridge University Press.

IPCC, 2022a: Summary for Policymakers [H.-O.Pörtner, D.C.Roberts, E.S.Poloczenska, K.Mintenbeck, M.Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (eds.)]. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [H.-O.Pörtner, D.C.Roberts, M.Tignor, E.S.Poloczenska, K.Mintenbeck, A.Alegría, M.Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3–33, doi:10.1017/9781009325844.001

IPCC, 2022b: Summary for Policymakers. In: *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.001.

Jellesmark, S. *et al.* (2021) ‘A counterfactual approach to measure the impact of wet grassland conservation on UK breeding bird populations’, *Conservation Biology*, p. cobi.13692. Available at: <https://doi.org/10.1111/cobi.13692>.

Johnson, J.A. *et al.* (2020) *Global Futures: modelling the global economic impacts of environmental change to support policy-making*. Technical Report. Available at: <https://www.wwf.org.uk/globalfutures>.

Kettenring, K.M. and Adams, C.R. (2011) ‘Lessons learned from invasive plant control experiments: a systematic review and meta-analysis: Invasive plant control experiments’, *Journal of Applied Ecology*, 48(4), pp. 970–979. Available at: <https://doi.org/10.1111/j.1365-2664.2011.01979.x>.

Keys, P.W. *et al.* (2019) ‘Anthropocene risk’, *Nature Sustainability*, 2(8), pp. 667–673. Available at: <https://doi.org/10.1038/s41893-019-0327-x>.

Kim, H. *et al.* (2018) ‘A protocol for an intercomparison of biodiversity and ecosystem services models using harmonized land-use and climate scenarios’, *Geoscientific Model Development*, 11(11), pp. 4537–4562. Available at: <https://doi.org/10.5194/gmd-11-4537-2018>.

Kim, HyeJin (2022) *Enhancing the use of scenario-based biodiversity information in conservation policy and practice*. Halle (Salle): Martin Luther University Halle-Wittenberg. Available at: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwivoICMl7j9AhVYgVwKHezeBucQFnoECAwQAQ&url=https%3A%2F%2Fopendata.uni-halle.de%2Fbitstream%2F1981185920%2F88202%2F1%2FPromotionsarbeit_HyeJin%2520Kim_31May2022.pdf&usg=AOvVaw3-jREGR-juGdOGlC9UIXm.

Kinzig, A.P. *et al.* (2013) ‘Social Norms and Global Environmental Challenges: The Complex Interaction of Behaviors, Values, and Policy’, *BioScience*, 63(3), pp. 164–175. Available at: <https://doi.org/10.1525/bio.2013.63.3.5>.

Knowlton, N. (2019) 'Earth Optimism—recapturing the positive', *Oryx*, 53(1), pp. 1–2. Available at: <https://doi.org/10.1017/S0030605318001333>.

Konno, K. and Pullin, A.S. (2020) 'Assessing the risk of bias in choice of search sources for environmental meta-analyses', *Research Synthesis Methods*, p. jrsm.1433. Available at: <https://doi.org/10.1002/jrsm.1433>.

Lambin, E.F. and Meyfroidt, P. (2011) 'Global land use change, economic globalization, and the looming land scarcity', *Proceedings of the National Academy of Sciences*, 108(9), pp. 3465–3472. Available at: <https://doi.org/10.1073/pnas.1100480108>.

Lauerburg, R.A.M. *et al.* (2020) 'Socio-ecological vulnerability to tipping points: A review of empirical approaches and their use for marine management', *Science of The Total Environment*, 705, p. 135838. Available at: <https://doi.org/10.1016/j.scitotenv.2019.135838>.

Lazar, J.G. *et al.* (2015) 'Beaver Ponds: Resurgent Nitrogen Sinks for Rural Watersheds in the Northeastern United States', *Journal of Environmental Quality*, 44(5), pp. 1684–1693. Available at: <https://doi.org/10.2134/jeq2014.12.0540>.

Leadley, P. *et al.* (2014) 'Interacting Regional-Scale Regime Shifts for Biodiversity and Ecosystem Services', *BioScience*, 64(8), pp. 665–679. Available at: <https://doi.org/10.1093/biosci/biu093>.

Leadley, P. *et al.* (2022) 'Achieving global biodiversity goals by 2050 requires urgent and integrated actions', *One Earth*, 5(6), pp. 597–603. Available at: <https://doi.org/10.1016/j.oneear.2022.05.009>.

Leclerc, D. *et al.* (2018) *Towards pathways of bending the curve of terrestrial biodiversity trends within the 21st century*. Vienne, Austria: International Institute of Applied Systems Research (IIASA). Available at: <https://doi.org/10.22022/ESM/04-2018.15241>.

Leclère, D. *et al.* (2020) 'Bending the curve of terrestrial biodiversity needs an integrated strategy', *Nature* [Preprint]. Available at: <https://doi.org/10.1038/s41586-020-2705-y>.

Liu, J. *et al.* (2018) 'Nexus approaches to global sustainable development', *Nature Sustainability*, 1(9), pp. 466–476. Available at: <https://doi.org/10.1038/s41893-018-0135-8>.

Lundquist, C.J. *et al.* (2017) *Visions for nature and nature's contributions to people for the 21st century*, p. 123.

Marques, A. *et al.* (2019) 'Increasing impacts of land use on biodiversity and carbon sequestration driven by population and economic growth', *Nature Ecology & Evolution*, 3(4), pp. 628–637. Available at: <https://doi.org/10.1038/s41559-019-0824-3>.

Martin, J., Chamaillé-Jammes, S. and Waller, D.M. (2020) 'Deer, wolves, and people: costs, benefits and challenges of living together', *Biological Reviews*, 95(3), pp. 782–801. Available at: <https://doi.org/10.1111/brv.12587>.

Martín-López, B. (2021) 'Plural valuation of nature matters for environmental sustainability and justice', *The Royal Society* [Preprint]. Available at: <https://royalsociety.org/topics-policy/projects/biodiversity/plural-valuation-of-nature-matters-for-environmental-sustainability-and-justice/> (Accessed: 5 July 2021).

McLauchlan, K.K. *et al.* (2020) 'Fire as a fundamental ecological process: Research advances and frontiers', *Journal of Ecology*. Edited by G. Durigan, 108(5), pp. 2047–2069. Available at: <https://doi.org/10.1111/1365-2745.13403>.

- Miller, B.W., Caplow, S.C. and Leslie, P.W. (2012) 'Feedbacks between Conservation and Social-Ecological Systems: *Conservation and Social-Ecological Systems*', *Conservation Biology*, 26(2), pp. 218–227. Available at: <https://doi.org/10.1111/j.1523-1739.2012.01823.x>.
- Miola, A. (2019) 'Measuring sustainable development goals performance: How to monitor policy action in the 2030 Agenda implementation?', *Ecological Economics*, p. 10.
- Mouquet, N. *et al.* (2015) 'REVIEW: Predictive ecology in a changing world', *Journal of Applied Ecology*. Edited by M. Cadotte, 52(5), pp. 1293–1310. Available at: <https://doi.org/10.1111/1365-2664.12482>.
- Nemogá, G.R., Appasamy, A. and Romanow, C.A. (2022) 'Protecting Indigenous and Local Knowledge Through a Biocultural Diversity Framework', *The Journal of Environment & Development*, 31(3), pp. 223–252. Available at: <https://doi.org/10.1177/10704965221104781>.
- Ning, Z. *et al.* (2021) 'Can the native faunal communities be restored from removal of invasive plants in coastal ecosystems? A global meta-analysis', *Global Change Biology*, 27(19), pp. 4644–4656. Available at: <https://doi.org/10.1111/gcb.15765>.
- O'Connor, L.M.J. *et al.* (2021) 'Balancing conservation priorities for nature and for people in Europe', *Science*, 372(6544), pp. 856–860. Available at: <https://doi.org/10.1126/science.abc4896>.
- O'Neill, B.C. *et al.* (2020) 'Achievements and needs for the climate change scenario framework', *Nature Climate Change*, 10(12), pp. 1074–1084. Available at: <https://doi.org/10.1038/s41558-020-00952-0>.
- van Oudenhoven, A.P.E. *et al.* (2018) 'Key criteria for developing ecosystem service indicators to inform decision making', *Ecological Indicators*, 95, pp. 417–426. Available at: <https://doi.org/10.1016/j.ecolind.2018.06.020>.
- Pacheco, A. and Meyer, C. (2022) 'Land tenure drives Brazil's deforestation rates across socio-environmental contexts', *Nature Communications*, 13(1), p. 5759. Available at: <https://doi.org/10.1038/s41467-022-33398-3>.
- Palacios-Abrantes, J. *et al.* (2022) 'Managing biodiversity in the Anthropocene: discussing the Nature Futures Framework as a tool for adaptive decision-making for nature under climate change', *Sustainability Science* [Preprint]. Available at: <https://doi.org/10.1007/s11625-022-01200-4>.
- Parmesan, C. *et al.* (2022) 'Terrestrial and Freshwater Ecosystems and Their Services', in *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK and New York, NY, USA: Cambridge University Press, pp. 197–377.
- Pascoe, S.D., Plagányi, É.E. and Dichmont, C.M. (2017) 'Modelling multiple management objectives in fisheries: Australian experiences', *ICES Journal of Marine Science*. Edited by S. Cadrin, 74(2), pp. 464–474. Available at: <https://doi.org/10.1093/icesjms/fsw051>.
- Pascual, U. *et al.* (2017) 'Valuing nature's contributions to people: the IPBES approach', *Current Opinion in Environmental Sustainability*, 26–27, pp. 7–16. Available at: <https://doi.org/10.1016/j.cosust.2016.12.006>.
- Pascual, U. *et al.* (2021) 'Biodiversity and the challenge of pluralism', *Nature Sustainability* [Preprint]. Available at: <https://doi.org/10.1038/s41893-021-00694-7>.
- PBL (2019a) *From visions to scenarios for nature and nature's contributions to people for the 21st century*. Workshop report 3756. The Hague: PBL Netherlands Environmental Assessment Agency.

PBL (2019b) *Global modelling of biodiversity and ecosystem services*. Workshop report 3798. The Hague: PBL Netherlands Environmental Assessment Agency.

Pereira, H.M. *et al.* (2013) 'Essential Biodiversity Variables', *Science*, 339(6117), pp. 277–278. Available at: <https://doi.org/10.1126/science.1229931>.

Pereira, H.M. *et al.* (2020) *Global trends in biodiversity and ecosystem services from 1900 to 2050*. preprint. Ecology. Available at: <https://doi.org/10.1101/2020.04.14.031716>.

Pereira, L. *et al.* (2019) 'Building capacities for transformative change towards sustainability: Imagination in Intergovernmental Science-Policy Scenario Processes', *Elem Sci Anth*, 7(1), p. 35. Available at: <https://doi.org/10.1525/elementa.374>.

Pereira, L. *et al.* (2021) 'Advancing a toolkit of diverse futures approaches for global environmental assessments', *Ecosystems and People*, 17(1), pp. 191–204. Available at: <https://doi.org/10.1080/26395916.2021.1901783>.

Pereira, L.M. *et al.* (2020) 'Developing multiscale and integrative nature–people scenarios using the Nature Futures Framework', *People and Nature*. Edited by B. Egoh, 2(4), pp. 1172–1195. Available at: <https://doi.org/10.1002/pan3.10146>.

Perino, A. *et al.* (2022) 'Biodiversity post-2020: Closing the gap between global targets and national-level implementation', *Conservation Letters*, 15(2). Available at: <https://doi.org/10.1111/conl.12848>.

Petchey, O.L. *et al.* (2015) 'The ecological forecast horizon, and examples of its uses and determinants', *Ecology Letters*. Edited by D. Vasseur, 18(7), pp. 597–611. Available at: <https://doi.org/10.1111/ele.12443>.

Polasky, S. *et al.* (2008) 'Where to put things? Spatial land management to sustain biodiversity and economic returns', *Biological Conservation*, 141(6), pp. 1505–1524. Available at: <https://doi.org/10.1016/j.biocon.2008.03.022>.

Pullin, A.S. and Stewart, G.B. (2006) 'Guidelines for Systematic Review in Conservation and Environmental Management', *Conservation Biology*, 20(6), pp. 1647–1656. Available at: <https://doi.org/10.1111/j.1523-1739.2006.00485.x>.

Regan, H.M., Colyvan, M. and Burgman, M.A. (2002) 'A taxonomy and treatment of uncertainty for ecology and conservation biology', *Ecological Applications*, 12(2), pp. 618–628. Available at: [https://doi.org/10.1890/1051-0761\(2002\)012\[0618:ATATOU\]2.0.CO;2](https://doi.org/10.1890/1051-0761(2002)012[0618:ATATOU]2.0.CO;2).

Ribas, L.G.S., Pressey, R.L. and Bini, L.M. (2021) 'Estimating counterfactuals for evaluation of ecological and conservation impact: an introduction to matching methods', *Biological Reviews*, p. brv.12697. Available at: <https://doi.org/10.1111/brv.12697>.

Robinson, D.T. *et al.* (2018) 'Modelling feedbacks between human and natural processes in the land system', *Earth System Dynamics*, 9(2), pp. 895–914. Available at: <https://doi.org/10.5194/esd-9-895-2018>.

Rocha, J. *et al.* (2020) 'Mapping social-ecological systems archetypes', *Environmental Research Letters*, 15(3), p. 034017. Available at: <https://doi.org/10.1088/1748-9326/ab666e>.

Rodrigues, A.S.L. and Cazalis, V. (2020) 'The multifaceted challenge of evaluating protected area effectiveness', *Nature Communications*, 11(1), p. 5147. Available at: <https://doi.org/10.1038/s41467-020-18989-2>.

Rosa, I.M.D. *et al.* (2017) 'Multiscale scenarios for nature futures', *Nature Ecology & Evolution*, 1(10), pp. 1416–1419. Available at: <https://doi.org/10.1038/s41559-017-0273-9>.

- Rosa, I.M.D. *et al.* (2020) ‘Challenges in producing policy-relevant global scenarios of biodiversity and ecosystem services’, *Global Ecology and Conservation*, 22, p. e00886. Available at: <https://doi.org/10.1016/j.gecco.2019.e00886>.
- Rounsevell, M.D.A. *et al.* (2021) ‘Identifying uncertainties in scenarios and models of socio-ecological systems in support of decision-making’, *One Earth*, 4(7), pp. 967–985. Available at: <https://doi.org/10.1016/j.oneear.2021.06.003>.
- Sala, E. *et al.* (2021) ‘Protecting the global ocean for biodiversity, food and climate’, *Nature*, 592(7854), pp. 397–402. Available at: <https://doi.org/10.1038/s41586-021-03371-z>.
- Sala, E. and Giakoumi, S. (2018) ‘No-take marine reserves are the most effective protected areas in the ocean’, *ICES Journal of Marine Science*. Edited by P. Linwood, 75(3), pp. 1166–1168. Available at: <https://doi.org/10.1093/icesjms/fsx059>.
- Schleicher, J. *et al.* (2020) ‘Statistical matching for conservation science’, *Conservation Biology*, 34(3), pp. 538–549. Available at: <https://doi.org/10.1111/cobi.13448>.
- Schmidt, P.M. and Peterson, M.J. (2009) ‘Biodiversity Conservation and Indigenous Land Management in the Era of Self-Determination’, *Conservation Biology*, 23(6), pp. 1458–1466. Available at: <https://doi.org/10.1111/j.1523-1739.2009.01262.x>.
- Schmitz, O.J. *et al.* (2018) ‘Animals and the zoogeochemistry of the carbon cycle’, *Science*, 362(6419), p. eaar3213. Available at: <https://doi.org/10.1126/science.aar3213>.
- Singh, G.G. *et al.* (2018) ‘A rapid assessment of co-benefits and trade-offs among Sustainable Development Goals’, *Marine Policy*, 93, pp. 223–231. Available at: <https://doi.org/10.1016/j.marpol.2017.05.030>.
- Sitas, N. *et al.* (2019) ‘Exploring the usefulness of scenario archetypes in science-policy processes: experience across IPBES assessments’, *Ecology and Society*, 24(3), p. art35. Available at: <https://doi.org/10.5751/ES-11039-240335>.
- Smith, R.J. *et al.* (2003) ‘Governance and the loss of biodiversity’, *Nature*, 426(6962), pp. 67–70. Available at: <https://doi.org/10.1038/nature02025>.
- Smokorowski, K.E. and Randall, R.G. (2017) ‘Cautions on using the Before-After-Control-Impact design in environmental effects monitoring programs’, *FACETS*. Edited by B. Favaro, 2(1), pp. 212–232. Available at: <https://doi.org/10.1139/facets-2016-0058>.
- Soto-Navarro, C.A. *et al.* (2021) ‘Towards a multidimensional biodiversity index for national application’, *Nature Sustainability*, pp. 1–10. Available at: <https://doi.org/10.1038/s41893-021-00753-z>.
- Stehfest, E. *et al.* (2019) ‘Key determinants of global land-use projections’, *Nature Communications*, 10(1), p. 2166. Available at: <https://doi.org/10.1038/s41467-019-09945-w>.
- Stout, T.L., Majerova, M. and Neilson, B.T. (2017) ‘Impacts of beaver dams on channel hydraulics and substrate characteristics in a mountain stream’, *Ecohydrology*, 10(1), p. e1767. Available at: <https://doi.org/10.1002/eco.1767>.
- Strassburg, B.B.N. *et al.* (2020) ‘Global priority areas for ecosystem restoration’, *Nature*, 586(7831), pp. 724–729. Available at: <https://doi.org/10.1038/s41586-020-2784-9>.
- Swartz, W. *et al.* (2010) ‘Sourcing seafood for the three major markets: The EU, Japan and the USA’, *Marine Policy*, 34(6), pp. 1366–1373. Available at: <https://doi.org/10.1016/j.marpol.2010.06.011>.

- Sze, J.S. *et al.* (2021) ‘Reduced deforestation and degradation in Indigenous Lands pan-tropically’, *Nature Sustainability* [Preprint]. Available at: <https://doi.org/10.1038/s41893-021-00815-2>.
- Tengo, M. *et al.* (2014) ‘Connecting Diverse Knowledge Systems for Enhanced Ecosystem Governance: The Multiple Evidence Base Approach’, p. 13.
- Tittensor, D.P. *et al.* (2017) ‘A protocol for the intercomparison of marine fishery and ecosystem models: Fish-MIP v1.0’, *Geoscientific Model Development Discussions*, pp. 1–39. Available at: <https://doi.org/10.5194/gmd-2017-209>.
- UNDESA (2021) *United Nations Global Sustainable Development Goals Database, SDG Indicators*. Available at: <https://unstats.un.org/sdgs/indicators/database/> (Accessed: 15 September 2021).
- UNSTATS (2022) ‘Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development’. United Nations Statistical Commission. Available at: <https://unstats.un.org/sdgs/indicators/indicators-list/>.
- Urban, M.C. *et al.* (2016) ‘Improving the forecast for biodiversity under climate change’, *Science*, 353(6304), pp. aad8466–aad8466. Available at: <https://doi.org/10.1126/science.aad8466>.
- Urban, M.C. *et al.* (2022) ‘Coding for Life: Designing a Platform for Projecting and Protecting Global Biodiversity’, *BioScience*, 72(1), pp. 91–104. Available at: <https://doi.org/10.1093/biosci/biab099>.
- Waldron, A. *et al.* (2017) ‘Reductions in global biodiversity loss predicted from conservation spending’, *Nature*, 551(7680), pp. 364–367. Available at: <https://doi.org/10.1038/nature24295>.
- Walters, M. and Scholes, R.J. (eds) (2017) *The GEO Handbook on Biodiversity Observation Networks*. Cham: Springer International Publishing. Available at: <https://doi.org/10.1007/978-3-319-27288-7>.
- Weiskopf, S.R. *et al.* (2022) ‘A Conceptual Framework to Integrate Biodiversity, Ecosystem Function, and Ecosystem Service Models’, *BioScience*, 72(11), pp. 1062–1073. Available at: <https://doi.org/10.1093/biosci/biac074>.
- Wilkinson, M.D. *et al.* (2016) ‘The FAIR Guiding Principles for scientific data management and stewardship’, *Scientific Data*, 3(1), p. 160018. Available at: <https://doi.org/10.1038/sdata.2016.18>.
- Willby, N.J. *et al.* (2018) ‘Rewilding wetlands: beaver as agents of within-habitat heterogeneity and the responses of contrasting biota’, *Philosophical Transactions of the Royal Society B: Biological Sciences*, 373(1761), p. 20170444. Available at: <https://doi.org/10.1098/rstb.2017.0444>.
- Willcock, S. *et al.* (2018) ‘Machine learning for ecosystem services’, *Ecosystem Services*, 33, pp. 165–174. Available at: <https://doi.org/10.1016/j.ecoser.2018.04.004>.
- Willcock, S. *et al.* (2020) ‘Ensembles of ecosystem service models can improve accuracy and indicate uncertainty’, *Science of The Total Environment*, 747, p. 141006. Available at: <https://doi.org/10.1016/j.scitotenv.2020.141006>.
- Wohl, E. (2013) ‘Landscape-scale carbon storage associated with beaver dams: CARBON STORAGE AND BEAVER DAMS’, *Geophysical Research Letters*, 40(14), pp. 3631–3636. Available at: <https://doi.org/10.1002/grl.50710>.

SUPPLEMENTARY MATERIALS

Towards a better future for biodiversity and people: modelling Nature Futures

Appendix A. Participants' perspectives on the application of Nature Futures Framework in scenarios and modelling (Source: 2019 Vancouver Stakeholder Workshop (PBL, 2019a))

This Appendix presents the responses to the two questions asked to the participants¹ of the Stakeholder Workshop "From visions to scenarios for nature and nature's contributions to people for the 21st century" on the new scenarios needed and important dynamics, variables, processes, feedbacks, or drivers that should be represented in them.

Question 1. *Based on your understanding of the Nature Future Framework, what new Nature Futures scenarios are needed (thinking especially of the ecosystem or area where you work, if applicable)?*

Question 2. *What are the most important dynamics, variables, processes, feedbacks or drivers that should be included in the next generation of scenarios, but are not well represented in existing scenarios?*

Responses

- Scenarios that explicitly consider indigenous and other ways of knowing
- How to overcome structural inequalities and power differentials to accommodate diversity and difference. Different ways of thinking about people, nature, and how they fit together (e.g. "Walking backwards into the future").
- Scenarios that allow for positive biodiversity options beyond 'protected areas', i.e., non-binary - e.g., better sustainable management
- Non-quantitative social and cultural ecosystem services (and societal and cultural values) - how do we model the things that we cannot quantify
- Scenarios that engage with business and industry interests and rights in ways that promote different ways of doing economy. Grounding work in practice and economy crucial for sustainability but usually not very well represented in scenarios
- Reconcile scale mismatches – especially across governance and biophysical regimes
- Shared Socio-economic Pathways (SSPs) and marine environment - how different ocean management can help us achieve different dimensions of ocean sustainability
- People interactions with oceans at regional and global scales besides fishing (e.g., pollution, recreational activities); Interaction of climate change and oceans dynamics beyond fishing (also marina pollution, deep sea fishing, recreation); Differences among regions, ways of living; Inclusion of idiosyncratic ways of living among regions
- How changes in people's behaviour could change ocean dynamics (further research) and how changes in people's experience of nature change nature (next few years).
- Scenarios that incorporate the impact of knowledge/ignorance of nature, including e.g. loss/revival of traditional knowledge; scenarios that incorporate impact of knowledge, biodiversity literacy as educational priority, feedbacks for health and nutrition, public engagement through citizen science, conservation volunteering > awareness/consciousness > mainstreaming as a political issue, culture of data/information sharing > improved science to inform nature-friendly policies. How culture of data sharing can improve production of science itself.
- Species-focused scenarios that include dynamics of ecosystems and human interactions, evolving conservation strategy, proxies to human wellbeing.
- Complex scenarios that address impact of invasive species on ecosystems and integrated to broader social-ecological scenarios.
- Scenarios that incorporate nature conservation goals and sectoral development (especially, agriculture).
- Interaction with human impact and desired transformation of human relations with nature. (*How human can transform relations with nature in order to significantly reduce negative impact*)
- "Nature for nature": Rewilding and novel Anthropocene ecosystems: need to incorporate what nature could be (not just humans doing things with/to nature or not).

¹ For the list of participants, please see the Annex 1 of PBL, 2019a. From visions to scenarios for nature and nature's contributions to people for the 21st century (Workshop report No. 3756). PBL Netherlands Environmental Assessment Agency, The Hague. [URL](#)

- What kind of nature do we want? - learning from the past and bringing back wildness for the animals and for people in the context of the Anthropocene
- Pluralism context - Different phases in “Policy Cycle” require different types of models & scenarios but tool development heavily biased towards ‘decisions’; let people who think differently about the world engage in the process, not simply focused on “decisions” (e.g., including co-management).
- Types of motivations (individual and institutional) to pursue specific types of behaviour, policies, etc. related to nature, ecosystems and biodiversity; Values underpinning decision-making processes; Link to value considerations in other IPBES processes
- Formation of the prevailing nature-related discourses due to the changes in business strategies, public opinion and the influence of opinion-makers. Influence of these discourses on indirect drivers of nature and NCP/ES change (culture, policy, diets, ...)
- Blue justice (and critical engagement with the sea as a humankind common heritage); range shifts of species, communities, fleets;
- Inclusion of fishing communities’ ways of resilience, adaptation, nature conservation x industrial use of coastal and riverine zones in scenarios; different types of dependency on the natural resources; application of different governance strategies for BBNJ (and deep seabed); Incorporation of good fisheries management within EEZ (economic exclusive zones)
- Climate change; Gender, inequality
- Scenarios that explicitly address degrowth paradigm which can be defined as “an equitable downscaling of production and consumption that increases human well-being and enhances ecological conditions at the local and global level, in the short and long term” (Schneider et al. 2010:512).
- Scenarios that explicitly address depopulation and shrinking (compacting) cities and their impacts on NCP and human wellbeing (Aging and depopulation in rural areas; Feedback between land and ocean through nutrient and material flow incl. Pollution; Mental health and greenspace; cross cutting points: multiple-feedbacks (incl. combined feedback)).
- Scenarios explicitly addressing the linkages between peoples’ relationship with nature and how they value nature - and nature outcomes such as how changes in land-use and migration reshape peoples’ interactions with nature (e.g. urbanisation, intensification of land (water) use, migration to new landscapes)
- Scenarios exploring peoples’ emotional relation to the ‘products’ of nature; the degree of materialism/consumerism across generations, socio-economic classes and value traditions and what dynamics this creates over space and time.
- Direct experiences with nature on human well-being and their feedback on value frameworks for nature; Investment in and access to education in general and environmental education in particular. Rise of populist parties, xenophobia, nationalism, lack of trust in science, human rights violations such as civic freedoms related to likelihood for pro-nature policies
- In my country the vision of “Vivir bien” has been emphasised, but this concept has not been made concrete in models or scenarios. The scenarios needed are those that measure the resilient capacity of cultures, integrate indigenous and local knowledge with scientific knowledge, address the effect of change of indigenous and local knowledge, and those that can be applied to policies affecting biodiversity and ecosystem functions in real and inclusive terms.
- These new scenarios should cover how inequality in land ownership shapes land use dynamics, including the opportunities generated for good use. They should illustrate how public policy generation and economic interests affect the resilience of local communities and society at large. They should cover transitions of realities without generalizing them and incorporate changes especially in socioeconomic terms.
- New scenarios should explicitly address revenue/earning models reshaping how chain parties interact with nature. They should address pollution by agrochemicals (pesticides, fertilizers) and show how this affects biodiversity. They should also address improvements/investments in (nature) education and technological development, as well as the role of nature education in people's experience of nature and how these change over time. We also need scenarios that address the extent to which all parties (government, chain-parties, financiers, landlords etc.) facilitate, stimulate, value, and reward land-users to stimulate nature/biodiversity.
- The new scenarios should cover how pollution/agrochemicals impact biodiversity (i.e. life in soil, water natural pest control, and pollination) in terms of volume of pesticides and level of hazard. They should also indicate how changes in nature education impact people’s experience of nature change, as well as how

activities in the open space outside the city (infrastructure, inland waterways, energy projects, recreation, industrial) shapes biodiversity.

- It is tricky to answer the question of how to incorporate different regional and temporal scales, so this requires discussions. We need scenarios that incorporate cross-domain (land / sea) impacts and threats – including those that address some scale mismatches across those two spheres of work. We would also need new scenarios that explicitly address socio-ecological responses to cumulative impacts (different scales, over time, and multiple stressors) - e.g., sedimentation.
- We need scenarios that include land-sea interactions, such as demand for food production. For example, with a future decline in agricultural production, can the demand be covered by food production in oceans and coastal areas?
- New scenarios should measure how activities on land impact the sea life (i.e. sediment, plastic, and nutrients), and how ocean governance and international trade impact fishing patterns.
- We need scenarios that look at the interactive impact of climate change and biodiversity either of biophysical and atmospheric effect on societies, or the impact of climate mitigation and adaptation on biodiversity – as an attempt to link two systems of models to better inform policy decisions. We also need scenarios that look at the impact of large scale collective actions (e.g. diet/consumption change), and national decisions (e.g. large scale restoration) on what is perceived to have the potential to bend the curve on biodiversity and climate change (e.g. scaling up positive seeds of Anthropocene) – scenarios and models that decision makers can understand and take to their world in governments, businesses, etc.
- New scenarios should cover the impact of collective human actions on biodiversity change, identify specific targets on indirect drivers that countries can act upon, and show the cost of implementing policy decisions or conservation interventions.
- We need scenarios incorporating as indirect drivers the key global economic trends and implications for nature at regional / local scales. This would cover trade, financing, foreign direct investments, equity considerations, and linkages between nature and cultural / language diversity.
- Examples of variables related to global economic trends are: Macroeconomic trends (GDP growth and structure), international Trade (Commodity prices / terms of trade / export value & volume), Financing (Total debt / % of GDP / % of exports), and Foreign Direct Investments (Total FDI / Structure).
- Nature as Culture would show a strengthening of cultural traditions, with people going back to traditional land management and agricultural practices. In Nature for Society/People, people move to multi-functional ways of managing the landscape, with a lot of emphasis on regulating services, but also other ecosystem services. In Nature for Nature, there will be rewilding, with forest and wildlife coming back. We need to imagine these nature futures for different landscapes and what they would mean at global level, national level and for different sectors, and link them to local biodiversity models as models used for different scales are not the same. At the global level Integrated Assessment Models, but at local level, we would need local ecosystem models and knowledge.
- There seems to be a tension between diverse values and how the scenarios are discussed, caused by wanting to quantify everything. We need to focus on scenarios that have nature as a being with which we interact, rather than nature as an object being used. Difficulty identifying places where humans have positive influence on nature, so need to uplift examples of that (People's contributions to nature rather than just nature's contributions to people). Focus on food in cities is great as it is often underrepresented, but we should also address overall consumption of materials.
- New scenarios would need to respect and illustrate diverse ways of relating to nature, rather than having a quantitative and report-based focus. Ecological Footprinting could be replaced with Eco shed. It would also need to cover co-nurturing and interdependence, and positive impacts from humans to nature, including areas of stewardship rather than “protection” or “preservation”.
- We need new scenarios that address how people's specific daily actions can directly improve the outcome for biodiversity and nature, and overcome the current disconnect between people's daily actions and the environment. Scenarios should also address how Indigenous knowledge can be included in a meaningful way and highlight how leaving nature (habitat) intact can have co-benefits for climate change reduction.
- The new scenarios should measure how activities by urbanites can impact biodiversity and identify what are the main drivers/ motivation for taking action. They should also cover the feedback of how changes in environmental health affect human health, including psychological wellbeing, as well as how people value certain species or issues, and influence their outcome.

- The new scenarios need to address freshwater biodiversity, as it is not well addressed, particularly in global scenarios. They should also cover invasive species, trade and trade agreements, and the interactions between biodiversity, ecosystem function and service. This is needed in order to move beyond ecosystem structure and function, and to show the role of biodiversity itself in maintaining ecosystem function in the face of uncertainty (e.g., resilience - option and insurance value).
- I would like to know how these new nature future scenarios will align with the new generation of scenarios representing integrated pathways to the SDGs and beyond (in the TWI2050 and other contexts). I see these nature futures perspectives as kind of “archetypes” beyond Global and Regional Sustainability, beyond the SSP1 single narrative. We would need new scenarios that explicitly deal with how these three perspectives on nature affect human wellbeing. For instance: rural-urban interactions and inequality (half earth, urbanization, actors, jobs) under different perspectives of nature in considering different contexts.
- The new scenarios should cover how inequality in land ownership (concentration) shapes land use dynamics and its impacts (on health, pesticides, etc), local/global interaction and feedbacks (market certifications affecting different actors, local policies, trade, agreements, land tenure regimes, etc.) in global models and in multi-scale scenarios.
- How biodiversity is the base for ecosystem function and how it can be integrated over the long term & how it can be used to influence social policies; how to integrate BES in socio economic benefits in a way that we can use the function to influence social policies
- We need scenarios that further explore how biodiversity is the base for ecosystem functioning, and how these processes and feedback can be integrated over the Long-term.
- I consider important also to continue exploring how Biodiversity and Ecosystem Services have an underpinning role in socioeconomic development and human well-being, to Influence short and long-term policies aiming to the protection of nature.
- 1) Transformative change (not only within the system, but also to alternative systems); 2) other big societal transitions (etc. populism / nationalism / politics; and digital transformations (AI, machine learning etc) influencing energy demands, employment etc.; 3) Cross cutting issues: gender, intersectionality.
- Relationship of humans with technology
- Cross-scale dynamics
- Hybrid natures, technology that nature has, what does this look like in the future; complex dynamics, global narratives, post 2020 agenda.
- We need scenarios that explicitly address how urbanism is reshaping how people interact with nature and shape regional and global dynamics.
- We need conservative (cultural-historic identity, heritage, value - native biodiversity) AND progressive (dynamism, emergence, reorganization) nature futures scenarios.
- Integrated, spatial heterogeneous, cross-scale scenarios
- 1. Spread of invasive species - people's perceptions of "wild" versus biodiversity. 2. Assessing biocultural diversity (land as culture, culture as land). 3. Inequality and land ownership - look at failures of conservation and what can we learn from them (look beyond poverty as causes)
- Relationship B and rewilding is important to understand; tolerance from behavioural point of view is great, attractive in large parks; commonality theories of nature than recognized, land is culture, culture is land; inequality and land ownership: need to look at failures of nature conservations (poverty), big losses have to do with conservation failure to deliver on promises to people, moving people out of parks etc. (3 challenges)
- Rewilding in contrast with urbanisation
- Rural areas with high cultural and natural heritages
- Social, technical, economic innovations
- Business strategies
- Social inclusiveness
- Methodological challenges arising from discussions with modellers
- From SSPs, businesses as partners (not just ‘enemies’ of nature), role that oceans play, how indigenous knowledge is critical

Appendix B. Identifying indicators for the three Nature Futures value perspectives

This Appendix documents the tables of indicators drafted by the participants of the Stakeholder Workshop “From visions to scenarios for nature and nature’s contributions to people for the 21st century” and of the Modellers² Workshop ‘Global Modelling of Biodiversity and Ecosystem Services’, followed by additional tables conceptualized by the authors intersecting the NFF with the IPBES Conceptual Framework. The numbers in the table are the ranks or priorities of importance.

Source: 2019 Vancouver Stakeholder Workshop (PBL, 2019a)

		Nature for Nature	Nature for Society	Nature as Culture
OCEAN				
Management	Total sustainable catch		↗ (1)	
	% fish from aquaculture			
	Level of management decision	Global		Local
	Area with no-take marine protected area	↗ (2) 30%		
	Area under community-based management			↗ (3)
State	% fish stocks depleted	↘ (All stocks)	↘ (Commercial stocks)	↘ (Culturally important stocks)
	% species endangered	↘ (1)		
	Status of culturally important species	↗		↗ (2)
	Area of wetland & mangroves	↗ (3)	↗	
Benefit	Carbon sequestration		↗ (2)	
	Dietary needs met			
	Number of jobs		↗ (3)	
	Recreation in nature			
	Livelihoods			↗ (1)
	Social cohesion			↗
LAND				
Management	Level of management decision	Global		Local
	Area under community-based management			↗ (1)
	Area under rewilding	↗ (2)		
	Wilderness protected area	↗ (3)		
	Invasive species	↘ (4)		
State	% endangered species	↘ (1)	↘	↘
	Status of culturally important species			↗ (2)
Impact	Clean water		↗ (1)	
	Carbon sequestration		↗	
	Soil protection		↗	
	Pollination		↗	
	Timber provision		↗	
	Local crops and breeds			↗ (3)
	Sustainable bushmeat			↗ (4)
	Dietary needs met	↗	↗	↗
	Number of jobs (ecotourism, agriculture, recreation)		↗ (2)	

² For the list of participants, please see the Annex 1 of PBL, 2019b. Global modelling of biodiversity and ecosystem services (Workshop report No. 3798). PBL Netherlands Environmental Assessment Agency, The Hague. [URL](#)

	Recreation in nature		↗ (3)	
URBAN				
Drivers	Density of city	High (1)		Low
	% of people in cities	High (2)	Medium – High	Low
	Distribution of city SAD?	Medium	Medium	Small
	Remote responsibility	↗ ↗ ↗		
	Green spaces that are self-sustained	↗		
Pressure	Air quality regulation	↗	↗ (1)	
	Water quality regulation (waste water management)	↗	↗ (2)	
	Community gardening			↗ (2)
	Urban gardening		↗	
	Green roofs / nature-based solution		↗	
	Level of management decision	Global		Local
State	Species richness (no-take species)	↗		
	Status of culturally important species			↗
	Area of green spaces	↗ Natural green spaces	↗ Functioning green spaces (3)	↗ Cultural green spaces
Impact	Number hours commute	↘	↘	↘ ↘ ↘
	Mode of commute	Mass transportation, biking		
	Equity	↗	↗	↗
	Mode of entry supply	Central	Renewable	Local
	Accessibility to green areas	Good for large	Depends on function	Small green and close (1)
	Hours of nature education	↗ Biodiversity	↗ ES	↗ Bioculture

Source: 2019 The Hague Modellers Workshop (PBL, 2019b)

	Management	State	Benefit
<i>Nature for Nature</i>	<i>Indicator: Protected areas</i> Marine: WDPA - No take Terrestrial: WDPA 1-3	<i>Endangered sp. and habitat</i> M: Endangered species, Coral reef cover T: endangered sp., pristine forest, wetland extent apex predators; megaherbivores; "trophic rewilding"	M: diving sites T: wildlife watching
<i>Nature for Society</i>	<i>Sustainable use areas</i> M: Mgmt effectiveness (country level) T: WDPA 4-6	M: % depleted stocks T: CO2 sequestration, water purification, soil retention nature-based solution	M: Sustainable fish catch T: Ag production w/o erosion or water pollution, storm protection
<i>Nature as Culture</i>	<i>Comm-based mgmt</i> M: Comm. Based mgmt (country reports) T: WDPA Comm. Based Mgmt. Do changes relate to the perceptions/values of the governing legal/government systems rather than of the people living in a particular	<i>Cultural keystones</i> M: status of culturally important species T: status of culturally important species, cultural landscapes social indicators; cultural support; such as cultural festivals cultural landscape certified food production - appellation	<i># Jobs (livelihoods?)</i> M: number of jobs T: local livelihoods books; cultural roles; shaman; cultural activities co-management; local control over nature; social-ecological feedbacks

	location? sacred forests? indigenous land	UNESCO world heritage sites, <i>maybe</i> <i>MABs and indigenous reserves, certain</i> <i>certifications</i>	
--	---	--	--

Source: Illustrative examples during the follow-on consultation post-workshops in drafting this paper

	Indicators - data, information and knowledge	Nature for Nature - Rewilding Nature	Nature for Society - Circular Economy	Nature as Culture - Sustainable Food
INTERVENTIONS	Projects funded in rewilding abandoned land	•		
Institutions	Incentives for sustainable food production		•	
Governance	Public-private collaboration on implementing circular economy			•
Anthropogenic asset				
DIRECT DRIVERS	Land and sea conserved and restored	•	•	•
Natural	Climate regulation	•	•	•
Anthropogenic	Pollution control (water, soil, air)	•	•	•
	Infectious disease control	○	•	○
	Reduced exploitation of natural resources		○	•
NATURE	Genetic diversity	•	•	•
Biodiversity	Species diversity	•	•	•
Ecosystem	Natural ecosystem extent	•	•	•
	Frequency and magnitude of ecosystem disturbance	•	•	•
	Ecosystem resilience	•	•	•
	Biomass	•	•	•
	Primary productivity	•	•	•
NATURE'S CONTRIBUTIONS TO PEOPLE	Crop and livestock production / fish catch		•	○
Material	Water quantity and quality	•	•	•
Regulating	Carbon storage	•	•	•
Non-material	Erosion control	•	•	•
	River flood/coastal risk reduction	•		•
	Access to green	•	•	
	Nature-based cultural heritage	•	•	○
GOOD QUALITY LIFE	Safe shelter			○
	Adequate nutrition		•	
	Mental and physical health	•	•	
	Nature-based recreation	•	○	
	Stewardship	•	•	•
	Social cohesion		•	•

	Indicators of data, information and knowledge	Nature for Nature	Nature for Society	Nature as Culture
Interventions (policy, management)	Expansion of protected area	High	Low	Med
	Increased community-based management	Med	Med	High
	Aquaculture for sustainable fish harvest	Med	High	Low
	Conservation of UNESCO World Heritage Sites	High	High	High
	Management of conservation sites	High	Med	Low
	Incentives for local food production and consumption	High	High	High
	Waste water management	High	High	Med
	Nature-based solutions (e.g. green roofs, solar power)	High	High	High
	Community & urban gardening	Med	High	High
State of Nature (biodiversity, ecosystems)	% species endangered	High	Med/low	Med/low
	% fish stock depleted from oceans	Low	High	Med
	% culturally important species preserved	Low	Med	High
	Genetic diversity of crops	High	Med	Med
	Extent of natural ecosystems (forest, wetland, etc.)	High	Med	High
	Abundance of pollinator and pollination	Med	High	Low
	Water purification	High	High	Med
	Soil retention	High	High	Med
Nature's Contributions to People (regulating, material, non- material)	Sustainable and healthy food and feed	High	High	High
	Clean air, clean water	High	High	Med
	Timber provision	Low	High	Med
	Green jobs (ecotourism, aquaculture, recreation)	High	Med	Med
	Maintenance of cultural heritage	Med	Low	High
	Accessibility to green area / recreation in nature	High	Med	High
	Human health	High	High	High
	Social cohesion	Low	Med	High

Appendix C. Assessing a single policy using the Nature Futures Framework and indicators

(Source: 2019 Vancouver Stakeholder Workshop (PBL, 2019a))

This Appendix documents the figures drafted by the participants of the Stakeholder Workshop “From visions to scenarios for nature and nature’s contributions to people for the 21st century” in assessing a single policy using the Nature Futures Framework with indicators on three themes “Species”, “Habitat/Landscape” and “Livelihoods”.

‘Species’ unpacked along the value perspectives

‘Habitat/Landscape’ unpacked along the value perspectives

‘Livelihoods’ unpacked along the value perspectives

Appendix D. Assessing a suite of policies using the Nature Futures Framework and models

(Source: 2019 Vancouver Stakeholder Workshop (PBL, 2019a))

This Appendix presents the figures drafted by the participants of the Stakeholder Workshop “From visions to scenarios for nature and nature’s contributions to people for the 21st century” in illustrating the systems dynamic modelling for Nature Futures scenarios (first three) and additional draft figures conceptualized by the authors through iteration, intersecting the NFF with DPSIR and the IPBES Conceptual Framework.

- Individual species of particular conservation concern (e.g. Red List species) 😊😊😊
- Conservation of overall species diversity 😊😊

- Particular service-providing species, or groups of species (e.g. pollinators) 😊
- Overall species diversity -> maintenance of ecosystem function/services

- Particular species of cultural significance
- Overall species diversity – cultural value?

Source: Illustrative examples during the follow-on consultation post-workshops in drafting this paper

Appendix E. Modellable questions for Nature Futures scenarios and their assessment on relevance, novelty and feasibility (Source: 2019 The Hague Modellers Workshop (PBL, 2019b))

This Appendix presents key questions for the Nature Futures scenarios modelling conceptualized by the experts of the Modellers Workshop ‘Global Modelling of Biodiversity and Ecosystem Services’ with an assessment on their relevance, novelty and feasibility with a view on the scale, models, and policy impact.

Nature for Nature

1. Under what social-economic context/governance/climate change mitigation would protected area and other area-based conservation measures improve biodiversity and impacts/trade-offs to society in the future?

- Under what conditions (consistent with SSPs, including transboundary cooperation) would ambitious area-based conservation targets be possible?
- How protecting 50% of biomes affects biodiversity and ecosystem services?
- What has been the impact of protected areas on larger landscape biodiversity and people?
- What are the non-terrestrial tools for future conservation?

Scale: Limit to global scale

Model: Available to address this question (model intercomparison using a suite of models looking at multiple dimensions of biodiversity)

Policy impact: CBD discussion of targets and goals

2. How would the restoration of abandoned agricultural landscape increase biodiversity and their implications for sustainable food and timber production elsewhere?

- How ecological corridors around human-managed systems improve biodiversity?

Scale: Global scale and larger regional case studies

Model: In principle, existing models are possible to address this question (vegetation cover/structure linking with species composition and biome shift)

Policy impact: Yes, particularly on restoration vs afforestation and nature-based solutions; also boundary of nature for nature.

3. Would climate change over-ride the positive effects of protected area/other land/ocean policies for biodiversity conservation?

Scale: Local to global

Model: Yes, models are ready to address this question

Policy impact: Relevant to design management of protected areas and informing the level of National-Determined Contributions needed.

4. Restoration of ecosystems and effects on biodiversity

- What kind of long term forest and environment transition (restoration of forest) can reduce biodiversity loss and hasten nature’s recovery?
- What are the optimal restoration mechanisms in different ecosystems? What are the cost implications in implementing them?
- How would reintroduction of species from zoos affect biodiversity?

Scale: Local to global

Model: Models are available to address the first sub-question, maybe for the second, and probably not for the third sub-question

Policy impact: Relevant to restoration-related policies.

5. Can minimizing invasive species, overexploitation and pollution prevent all species in the world from becoming endangered and maintain ecosystem integrity under projected climate change and population growth?

Scale: Global

Model: Yes, models are available

Policy impact: Yes, for global conservation policies

6. How/whether interventions related to global trade can minimize extinction risks and maintain/restore biodiversity?

Scale: Global

Model: Yes, methods/models are available

Policy impact: A range of effective conservation/trade related policies for biodiversity conservation

7. Do environmental/ecological education improve nature protection?

Scale: Local

Model: Possible qualitative social-ecological model

Policy impact: Relevant to local environmental policy

Nature for Society

1. Original: Does this perspective result in perverse biodiversity outcome?

Revised: Does managing the world for ES result in changes (increases or declines) in biodiversity, and how does that vary by types of biodiversity?

Rating: Very important, moderately difficult, dependent on ES

2. How do/can ecosystem services contribute to the regional economy?

Rating: Very important, relatively easy (if ecosystem services is known)

3. Original: Can you simulate in IAMs which landscape manages biodiversity better?

Revised: Can you incorporate a wide variety of management approaches to enhance ecosystem services (and their ecological implications) into IAMs?

Rating: Very important, difficult

4. Original: What ecosystem services can be minimized/reduced for conservation – identify over consumption areas and ecosystem service types

Revised: Trade-offs between ES and biodiversity. How can you find a combination of provisioning services while having enough regulating services?

5. Original: Can we sustainably harvest fish without any species becoming endangered and maintaining ecosystem integrity?

Revised: Can we sustainably harvest fish without any economically important species becoming endangered and maintaining ecosystem integrity such that ES are not compromised?

Rating: Important, moderately difficult

6. Original: How would improving biodiversity in the agricultural landscape impact the level, resilience, and distribution of ecosystem services?

Revised: How would improving biodiversity (crops, livestock, wild) in agricultural landscapes impact the level, resilience, and distribution of ecosystem services?

Rating: Important, difficult, some aspects (e.g., resilience), geographies, and relationships (wild biodiversity and ag.) very difficult

7. Original: What kind of ecological and economic development pathways can yield human nature outcomes congruent with all nature-based outcomes?

Revised: How do we define win-win scenarios, including more diverse social- ecological interconnections? And then, how do we identify the pathways to those solutions?

Rating: Deep interconnections: Essential, very difficult; Shallow interconnections: Important, relatively easy

8. Original: Can the ecological pressure be kept low enough in intensive systems to prevent severe feedback?

Revised: What level of ecological simplification is sustainable, and avoids undesirable human impacts?

Rating: Important, very difficult

9. Aquaculture vs wild catch

Rating: Important, not difficult

10. Original: How does/will a transition to responsible consumption affect the economy regionally?

Revised: How do changes in human behaviour (e.g., consumption) affect the regional economy, ecosystems, and land use, and thus ES?

Rating: moderately important, moderately difficult

11. Same as #10 but focusing on health and other socio-economic aspects (How does/will a transition to responsible consumption affect the economy regionally?).

Rating: Less important (for IPBES), difficult

12. Original: How would transformation to largely plant based consumption affect biodiversity and other ecosystem services?

Rating: Not essential, relatively easy

13. How do we incorporate urban areas and infrastructure into models of biodiversity and ecosystem services?

Nature as Culture

- How would diverse and locally sourced diets affect biodiversity and ecosystem services?
 - Key indicator: indicators biological/cultural/linguistic/agricultural/diet diversity
 - Diversity in agriculture (crops, livestock). Expand LU to build in diversity in crop type in IAMs as well as effects of crop type on biodiversity. PREDICTS is doing with crop management.
 - Measures of genetic diversity of crops (FAO has some info).
 - Localising diets/food miles/supply chain.
 - Maintenance of cultural/social component of diet
- How will cultural landscapes (including sacred sites) be affected by climate change and other drivers? Traditional agricultural landscapes such as landscaped terraces in Papua New Guinea, Satoyama/Japan, ancient Mediterranean cultural landscapes. Drivers: sea level rise, erosion, abandonment, rewilding
- How do traditional fisheries, maritime cultures, land-based traditional management and livelihoods affect biodiversity and ecosystem integrity? How do we model 'partial' protected areas/traditional land/sea management? How do global change impacts alter traditional fisheries without any species becoming extirpated and maintaining ecosystem integrity?
- How can we model cultural change and how do cultural feedbacks shape and are shaped by ecosystems?
- Is land sharing better for biodiversity and human well-being than land sparing - broader version of 'traditional management'?
- How do cultural landscapes affect different aspects of biodiversity and the ecosystem services they provide? Do we need to conserve or restore cultural landscapes?
- Can the idea of low intensity landscapes be combined with sufficient production for 9.5 billion people? [management intensity]
- Can biocultural thinking identify new global strategies or is it all context dependent?
 - Scaling up mosaic landscape on a global scale. Conceptually mosaic of multiple LU types at different scales e.g. could be communities each focussed on particular agricultural practice/strain/species.
 - Linking cultural diversity and biological/genetic diversity.
 - How different cultures react with agriculture/food?
 - More small scale/less intensive agriculture.e.g. French millet
 - Would farm-based selection of crops be an improvement vs single crop?
 - Is it important to maintain a biocultural relationship to improve/maintain biodiversity?
 - Long term resilience through potential reduction in crop yields -- probably larger footprint, less productive, but more resilience.

- What kind of societal change can contribute to sustain cultural (traditional) agricultural landscapes (e.g., ‘Satoyama’)? [Changes in dominant industrial/economic paradigm]
- How does close connection between nature and society affect human well-being? What are the well-being metrics, e.g. mental health benefits of interaction with nature vs sense of place, identity (NS hard to dissociate with NC)?
- How do changes in diversity/ecosystem health feedback on culture - feedback of nature to people, e.g. pastoral plain/organised/managed culture, like or dislike of open landscapes.
- How useful is rewilding in urban landscapes for biodiversity?

Scenario	Feasible (1 hard, 10 easy)	Novelty (1 low, 10 high)	Interest/Importance
Diet: <ul style="list-style-type: none"> • Diversity: maintaining genetic diversity of crops/resilience • Locally sourced: diets/food miles/supply chain • Traditional culture: would maintaining a traditional diet impact biodiversity 	Diversity: 4 (FAO cropland genetic diversity) Local source: 6 (transport across natural boundaries., can do local region, not direct relationship between local supply and GHG footprint) Traditional culture: 1 (possibly at very local scale)	10	10
Livelihood: <ul style="list-style-type: none"> • Cultural identity maintained (species still exist) • Influence of change/drivers 	Identity: 10 Drivers: 10	5	8
Cultural landscapes and biodiversity <ul style="list-style-type: none"> • Provision of BES • Resilience to drivers/climate change 	Local/regional: 10 (has been done) Global: 2 (how to scale up)	Local/regional: 5 Global: 10	10
Management intensity <ul style="list-style-type: none"> • Food production efficiency • BES contributions • Land sharing vs land sparing • Different types of PAs • Different spatial and temporal management regimes 	10 e.g. PREDICTS differentiate GLOBIO but many lump LU	Configuration and link to cultural landscape Local: 10 Global 10	10
Leverage points for restoring and/or maintaining cultural landscapes <ul style="list-style-type: none"> • Agricultural subsidies for diverse agro-cultural landscapes • PAs that include biocultural (Medellin) 	Local/regional: 9 Ocean models, econometric models (have subsidies)	5	7
Ecosystem benefits to people <ul style="list-style-type: none"> • Mental health (MH) • Sense of place/identity (SoP) 	MH: nature access/distance 10 (lots of data but not in scenarios) SoP: 2	MH: 8 SoP: 10	MH: 8 SoP: 10
Impacts of greening of urban spaces <ul style="list-style-type: none"> • Accounting for green space on BES. 	Local: 10 Global: 8	Local: 2 Global: 10	8

Cross-cutting

Ranking of questions

		Novelty	Feasibility	Global	Local
1	How would compact cities compare with low density cities on biodiversity and ecosystem services locally and globally?	XX	XXXX	X	XX
2	How does biodiversity and ecosystem services differ in cultural landscape and sustainably intensified landscape?	XX	XXXX	X	XXX
3	What are the conditions when economic development is compatible with nature conservation (what are the tools other than protected areas and CBNRM?)?		XX	XX	
4	How does having more no-take and sustainable-take areas compare with having sustainable harvest everywhere for livelihoods and biodiversity?	X	XX	XX	X
5	How can we model pathways for nature as support for economies and people (and identify new ways key path)?	XX	X		
6	How can we model the role of global capital finance in shaping local places?	XX			XX
7	What is the role of ownership of land and land tenure/ownership in nature futures?	X			XX
8	Are any of these perspectives incompatible with “desired” growth projections (population, GDP, etc.)?	XXX	XX	XXXX	
9	How do different perspectives of terrestrial and marine systems impact/feedback on each other?	XXXX	XX	XX	X
10	What can we learn for “successes” from each perspective? What enhances? What erodes? Trade-offs, synergies.	XXXX	X		X
11	What are the missing drivers of positive ecosystem change for the future (NFF Futures)?	XXXX	X	X	X
12	What are political economies that support each or erode nature future perspective?	XXXX	X	XXX	
13	Are the pathways similar for GDP and Human Development Indices (HDI) within the 3 nature future perspectives?	XXX		XX	
14	Is it possible to fulfil the needs for 9.5 billion people on half the land?		XXXX	XXX	

Clustering of questions (possible categories):

Aerial based measures	
1	How would compact cities compare with low density cities on biodiversity locally and globally and ecosystem services?
4	How does having more no-take and sustainable-take areas compare with having sustainable harvest everywhere for livelihoods and biodiversity?
14	Is it possible to fulfil the needs for 9.5 billion people on half the land?
Process based solutions	
2	How does biodiversity and ecosystem services differ in cultural landscape and sustainable intensified landscape?
Indirect drivers	

8	Are any of these perspectives incompatible with “desired” growth projections (population, GDP, etc.)?
11	What are the missing drivers of positive ecosystem change for the future (NFF Futures)?
Social-ecological feedbacks	
5	How can we model pathways nature as support for economies and people (and identify new ways key path)?
10	What can we learn for “successes” from each perspective? What enhances? What erodes? Trade-offs, synergies.
12	What are political economies that support or erode each nature future perspective?
Biodiversity and ecosystem services linkages	
1	How would compact cities compare with low density cities on biodiversity locally and globally and ecosystem services?
2	How does biodiversity and ecosystem services differ in cultural landscape and sustainable intensified landscape?
5	How can we model pathways nature as support for economies and people (and identify new ways key path)?
Management	
2	How does biodiversity and ecosystem services differ in cultural landscape and sustainable intensified landscape?
4	How does having more no-take and sustainable-take areas compare with having sustainable harvest everywhere for livelihoods and biodiversity?
6	How can we model the role of global capital finance in shaping local places?
12	What are political economies that support each or erode nature future perspective?
State	
2	How does biodiversity and ecosystem services differ in cultural landscape and sustainable intensified landscape?
4	How does having more no-take and sustainable-take areas compare with having sustainable harvest everywhere for livelihoods and biodiversity?
9	How do different perspectives of terrestrial and marine systems impact/feed-back on each other?
Benefits	
2	How does biodiversity and ecosystem services differ in cultural landscape and sustainable intensified landscape?
4	How does having more no-take and sustainable-take areas compare with having sustainable harvest everywhere for livelihoods and biodiversity?
12	What are political economies that support or erode each nature future perspective?

Appendix F. Glossary

Co-benefits: It refers to ‘the positive effects that a policy or measure aimed at one objective might have on other objectives, irrespective of the net effect on overall social welfare’ (IPCC, 2015; Mayrhofer and Gupta, 2016).

Drivers: the external factors that cause change in nature, anthropogenic assets, nature’s contributions to people and a good quality of life. They include institutions and governance systems and other indirect drivers, and direct drivers (both natural and anthropogenic) (IPBES, 2016).

Feedback: The modification or control of a process or system by its results or effects (IPBES online glossary accessed 4 January 2021). A negative feedback is one in which the initial perturbation is weakened by the changes it causes; a positive feedback is one in which the initial perturbation is enhanced (IPCC, 2015)

Frontiers: Nature Futures frontiers are where different combinations of interventions achieve substantive co-benefits to reach optimal and efficient states on all three nature value perspectives (Polasky et al., 2008).

Indicators: A quantitative or qualitative factor or variable that provides a simple, measurable and quantifiable characteristic or attribute responding in a known and communicable way to a changing environmental condition, to a changing ecological process or function, or to a changing element of biodiversity (IPBES online glossary accessed 13 May 2021).

Interventions: A change in policies or management practices that are aimed to protect, enhance or restore biodiversity, ecosystem services and their contributions to people.

Modelling: Development and use of models to translate scenarios into expected consequences for biodiversity and ecosystem services (IPBES methodological guide on scenarios and models 2017)

Models: Qualitative or quantitative representations of key components of a system and of relationships between the components (IPBES online glossary accessed 28 July 2020)

Narratives (or scenario narratives): Qualitative descriptions which provide the framework from which quantitative exploratory scenarios can be formulated (IPBES glossary10).

Nature Futures: Future states of nature that “represent a wide range of human–nature interactions, based on the perspectives of different stakeholders, and include a variety of different types of human-modified ecosystems encompassing different degrees of human intervention” (Rosa et al., 2017).

Nature Futures Framework (NFF) (Lundquist et al., In preparation): A heuristic that captures diverse, positive values for human-nature relationships in a triangular space.

Nature Futures value perspectives (Pereira et al., 2020): Three types of value perspectives on nature in Nature Futures Framework – intrinsic (also known as Nature for Nature), instrumental (Nature for Society), and relational (Nature as Culture) values. These nature values are not mutually exclusive and intricately intertwined by nature.

Pathways: Different strategies for moving from the current situation towards a desired future vision or set of specified targets. They are purposive courses of actions that build on each other, from short-term to long-term actions into broader transformation (Ferguson et al., 2013; Wise et al., 2014). The Three Horizons approach is often used to define such pathways in future visioning processes (Sharpe et al., 2016).

Policy space: Nature Futures policy space utilizes interventions and their representative indicators to score and map the system across value perspectives for a point in time or progress over two time points.

Regime shift: Substantial reorganization in system structure, functions and feedback that often occurs abruptly and persists over time (IPBES online glossary accessed 4 January 2021).

Retrospective evaluation (also known as ‘ex-post assessments’): is carried out to review the outcome of implemented policies and management, and can also be done through comparative scenarios or counterfactual analyses (IPBES 2016). Although valuable in enhancing transparent reporting and performance evaluation, retrospective analyses have been limited due to the challenges including environment-governance complexity, inadequate monitoring or the absence of enforcement systems (Haug et al., 2010). However, to improve the evidence base for policy decisions, retrospective evaluation is critical in informing the design and implementation of policies (Andam et al., 2008; Geldmann et al., 2019; Smismans, 2015).

Scenarios: Representations of possible futures for one or more components of a system, particularly for drivers of change in nature and nature’s benefits, including alternative policy or management options (IPBES online glossary accessed 28 July 2020)

Social-ecological systems: An ecosystem, the management of this ecosystem by actors and organizations, and the rules, social norms, and conventions underlying this management (IPBES online glossary accessed 4 January 2021).

State-space: The Nature Futures state-space is where all three nature value perspectives are enhanced simultaneously from the present-day conditions.

Synergies: Synergies arise when the enhancement of one desirable outcome leads to enhancement of another. Also see definition for “Trade-offs” (IPBES online glossary accessed 4 January 2021).

Tipping points: A set of conditions of an ecological or social system where further perturbation will cause rapid change and prevent the system from returning to its former state (IPBES online glossary accessed 4 January 2021).

Trade-offs: A trade-off is a situation where an improvement in the status of one aspect of the environment or of human well-being is necessarily associated with a decline in or loss of a different aspect. Trade-offs characterize most complex systems, and are important to consider when making decisions that aim to improve environmental and/or socio-economic outcomes. Trade-offs are distinct from synergies (the latter are also referred to as “win-win” scenarios): synergies arise when the enhancement of one desirable outcome leads to enhancement of another (IPBES online glossary accessed 4 January 2021).

Value: A principle or core belief underpinning rules and moral judgments. Values as principles vary from one culture to another and also between individuals and groups (IPBES/4/INF/13).
Value (as preference): A value can be the preference someone has for something or for a particular state of the world. Preference involves the act of making comparisons, either explicitly or implicitly. Preference refers to the importance attributed to one entity relative to another one (IPBES/4/INF/13, IPBES online glossary accessed 28 July 2020).

Visioning: “the process of creating a vision, i.e., a representation of a desirable future state, as opposed to scenario building (possible future states), forecasting (likely future states), and backcasting (pathways to desirable future states)” (Wiek and Iwaniec, 2014).

Visions: “Visions” are built on the different seed initiatives from which inspirational stories of sustainable, equitable futures can inspire us to move toward the values and ideals of a “good Anthropocene” (Bennett et al., 2016; Preiser et al., 2017). “Seeds” are innovative initiatives, practices and ideas that are present in the world today, but are not currently widespread or dominant (Bennett et al., 2016; Lundquist et al., 2017).

References

- Andam, K.S., Ferraro, P.J., Pfaff, A., Sanchez-Azofeifa, G.A., Robalino, J.A., 2008. Measuring the effectiveness of protected area networks in reducing deforestation. *Proceedings of the National Academy of Sciences* 105, 16089–16094. <https://doi.org/10.1073/pnas.0800437105>
- Bennett, E.M., Solan, M., Biggs, R., McPhearson, T., Norström, A.V., Olsson, P., Pereira, L., Peterson, G.D., Raudsepp-Hearne, C., Biermann, F., Carpenter, S.R., Ellis, E.C., Hichert, T., Galaz, V., Lahsen, M., Milkoreit, M., Martin López, B., Nicholas, K.A., Preiser, R., Vince, G., Vervoort, J.M., Xu, J., 2016. Bright spots: seeds of a good Anthropocene. *Frontiers in Ecology and the Environment* 14, 441–448. <https://doi.org/10.1002/fee.1309>
- Ferguson, S.M., Phillips, P.E.M., Roth, B.L., Wess, J., Neumaier, J.F., 2013. Direct-Pathway Striatal Neurons Regulate the Retention of Decision-Making Strategies. *Journal of Neuroscience* 33, 11668–11676. <https://doi.org/10.1523/JNEUROSCI.4783-12.2013>
- Geldmann, J., Manica, A., Burgess, N.D., Coad, L., Balmford, A., 2019. A global-level assessment of the effectiveness of protected areas at resisting anthropogenic pressures. *Proc Natl Acad Sci USA* 116, 23209–23215. <https://doi.org/10.1073/pnas.1908221116>
- Haug, C., Rayner, T., Jordan, A., Hildingsson, R., Strippel, J., Monni, S., Huitema, D., Massey, E., van Asselt, H., Berkhout, F., 2010. Navigating the dilemmas of climate policy in Europe: evidence from policy evaluation studies. *Climatic Change* 101, 427–445. <https://doi.org/10.1007/s10584-009-9682-3>
- IPBES, 2016. The methodological assessment report on scenarios and models of biodiversity and ecosystem services., IPBES Methodological Assessment Report on Scenarios and Models of Biodiversity and Ecosystem Services. Intergovernmental Platform on Biodiversity and Ecosystem Services.
- IPCC, 2015. Climate Change 2014: Impacts, Adaptation and Vulnerability, Volume 1, Global and Sectoral Aspects Working Group II Contribution to the IPCC Fifth Assessment Report. Cambridge University Press, Cambridge.
- Lundquist, C.J., Miguel, P., Henrique, D. P., Garry, Sylvia, K.-V., Laura, P., A, A., Lilibeth, Resit, A., H., William, C., K, D., Kathryn, Eefje, den B., Simon, F., Alison, G., Jennifer, H., HyeJin, K., Nicholas, K., Grygoriy, K., J, K., Jan, Paul, M., Jean, N, N., Karachepone, Sana, O., Gabriela, P., Maria, Ramón, P.-M., Federica, R., Carlo, R., Jyothis, S., A, S., Machteld, Rob, A., In preparation. A pluralistic Nature Futures Framework for policy and action.
- Lundquist, C.J., Pereira, H.M., Alkemade, R., den Belder, E., Carvalho Ribeiro, S., Davies, K., Greenaway, A., Hauck, J., Karlsson-Vinkhuyzen, S., Kim, H., King, N., Lazarova, T., Pereira, L., Peterson, G., Ravera, F., van den Brink, T., Argumedo, A., Arida, C., Armenteras, D., Ausseil, A.G., Baptiste, B., Belanger, J., Bingham, K., Bowden-Kerby, A., Cao, M., Carino, J., van Damme, P.A., Devivo, R., Dickson, F., Dushimumuremyi, J.P., Ferrier, S., Flores-Díaz, A., Foley, M., Garcia Marquez, J., Giraldo-Perez, P., Greenhaigh, S., Hamilton, D.J., Hardison, P., Hicks, G., Hughey, K., Kahui-McConnell, R., Karuri-Sebina, G., De Kock, M., Leadley, P., Lemaitre, F., Maltseva, E., de Mattos Scaramuzza, C.A., Metwally, M., Nelson, W., Ngo, H., Neumann, C., Norrie, C., Perry, J., Quintana, R., Rodriguez Osuna, V.E., Roehrl, C., Seager, J., Sharpe, H., Shortland, T., Shulbaeva, P., Sumaila, U.R., Takahashi, Y., Titeux, N., Tiwari, S., Trisos, C., Ursache, A., Wheatley, A., Wilson, D., Wood, S., van Wyk, E., Yue, T.X., Zulfikar, D., Brake, M., Leigh, D., Lindgren-Streicher, P., 2017. Visions for nature and nature’ s contributions to people for the 21 st century.

- Mayrhofer, J.P., Gupta, J., 2016. The science and politics of co-benefits in climate policy. *Environmental Science & Policy* 57, 22–30. <https://doi.org/10.1016/j.envsci.2015.11.005>
- PBL, 2019a. From visions to scenarios for nature and nature's contributions to people for the 21st century (Workshop report No. 3756). PBL Netherlands Environmental Assessment Agency, The Hague.
- PBL, 2019b. Global modelling of biodiversity and ecosystem services (Workshop report No. 3798). PBL Netherlands Environmental Assessment Agency, The Hague.
- Pereira, L.M., Davies, K.K., Belder, E., Ferrier, S., Karlsson-Vinkhuyzen, S., Kim, H., Kuiper, J.J., Okayasu, S., Palomo, M.G., Pereira, H.M., Peterson, G., Sathyapalan, J., Schoolenberg, M., Alkemade, R., Carvalho Ribeiro, S., Greenaway, A., Hauck, J., King, N., Lazarova, T., Ravera, F., Chettri, N., Cheung, W.W.L., Hendriks, R.J.J., Kolomytsev, G., Leadley, P., Metzger, J., Ninan, K.N., Pichs, R., Popp, A., Rondinini, C., Rosa, I., Vuuren, D., Lundquist, C.J., 2020. Developing multiscale and integrative nature–people scenarios using the Nature Futures Framework. *People and Nature* 2, 1172–1195. <https://doi.org/10.1002/pan3.10146>
- Polasky, S., Nelson, E., Camm, J., Csuti, B., Fackler, P., Lonsdorf, E., Montgomery, C., White, D., Arthur, J., Garber-Yonts, B., Haight, R., Kagan, J., Starfield, A., Tobalske, C., 2008. Where to put things? Spatial land management to sustain biodiversity and economic returns. *Biological Conservation* 141, 1505–1524. <https://doi.org/10.1016/j.biocon.2008.03.022>
- Preiser, R., Pereira, L.M., Biggs, R. (Oonise), 2017. Navigating alternative framings of human–environment interactions: Variations on the theme of ‘Finding Nemo.’ *Anthropocene* 20, 83–87. <https://doi.org/10.1016/j.ancene.2017.10.003>
- 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., van Vuuren, D., 2017. Multiscale scenarios for nature futures. *Nat Ecol Evol* 1, 1416–1419. <https://doi.org/10.1038/s41559-017-0273-9>
- Sharpe, B., Hodgson, A., Leicester, G., Lyon, A., Fazey, I., 2016. Three horizons: a pathways practice for transformation. *E&S* 21, art47. <https://doi.org/10.5751/ES-08388-210247>
- Smismans, S., 2015. Policy Evaluation in the EU: The Challenges of Linking *Ex Ante* and *Ex Post* Appraisal. *Eur. j. risk regul.* 6, 6–26. <https://doi.org/10.1017/S1867299X00004244>
- Wiek, A., Iwaniec, D., 2014. Quality criteria for visions and visioning in sustainability science. *Sustain Sci* 9, 497–512. <https://doi.org/10.1007/s11625-013-0208-6>
- Wise, R.M., Fazey, I., Stafford Smith, M., Park, S.E., Eakin, H.C., Archer Van Garderen, E.R.M., Campbell, B., 2014. Reconceptualising adaptation to climate change as part of pathways of change and response. *Global Environmental Change* 28, 325–336. <https://doi.org/10.1016/j.gloenvcha.2013.12.002>