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

HyeJin Kim[1,2], Garry Peterson[3], William W. L. Cheung[4], Simon Ferrier[5], Rob Alkemade[6,7], Almut Arneth[8], Jan J. Kuiper[3], Sana Okayasu[6], Laura Pereira[3,9,10], Lilibeth A. Acosta[11], Rebecca Chaplin-Kramer[12,13], Eefje den Belder[6,14], Tyler D. Eddy[15], Justin A Johnson[16], Sylvia Karlsson-Vinkhuyzen[17], Marcel T.J. Kok[6], Paul Leadley[18], David Leclère[19], Carolyn J. Lundquist[20,21], Carlo Rondinini[22], Robert J. Scholes[9], Machteld Schoolenberg[6], Yunne-Jai Shin[23], Elke Stehfest[6], Fabrice Stephenson[20], Piero Visconti[19], Detlef van Vuuren[6,10], Colette C.C. Wabnitz[4,24], Juan José Alava[4], Ivon Cuadros-Casanova[25], Maria A. Gasalla[26], Ghassen Halouani[27], Mike Harfoot[28], Shizuka Hashimoto[29], Thomas Hickler[30,31], Tim Hirsch[32], Grigory Kolomytsev[33], Brian W. Miller[34], Haruka Ohashi[35], Maria Gabriela Palomo[36], Alexander Popp[37], Roy Paco Remme[12,38], Osamu Saito[39], U. Rashid Sumalia[4,40], Simon Willcock[41,42], Henrique M. Pereira[1,2,43]

[1] German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Leipzig, Germany
[2] Martin Luther University Halle-Wittenberg, Halle (Salle), Germany
[3] Stockholm Resilience Centre, Stockholm University, Sweden
[4] Institute for the Fisheries and Oceans, University of British Columbia, Vancouver, Canada
[5] CSIRO Land and Water, Canberra, Australia
[6] PBL Netherlands Environmental Assessment Agency, The Hague, Netherlands
[7] Environmental Systems Analysis group, Wageningen University, The Netherlands
[8] KIT, Atmospheric Environmental Research, Garmisch-Partenkirchen, Germany
[9] Global Change Institute, University of the Witwatersrand, South Africa
[10] Copernicus Institute of Sustainable Development, Utrecht University, The Netherlands
[11] Climate Action and Inclusive Development Department, Global Green Growth Institute, Seoul, South Korea
[12] Natural Capital Project, Stanford University, Stanford, CA, USA
[13] Institute on the Environment, University of Minnesota, St Paul, MN, USA
[14] Agrosystems Research, Wageningen University, The Netherlands
[15] Centre for Fisheries Ecosystems Research, Fisheries & Marine Institute, Memorial University of Newfoundland, St. John's, Canada
[16] Department of Applied Economics, University of Minnesota, USA
[17] Public Administration and Policy Group, Wageningen University & Research, The Netherlands
[18] Ecologie, Systématique et Evolution, Université Paris-Saclay, CNRS, AgroParisTech, Orsay, France
[19] Biodiversity and Natural Resources (BNR) Program, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria
[20] National Institute of Water and Atmospheric Research (NIWA), Hamilton, New Zealand

[21] School of Environment, University of Auckland, New Zealand
[22] Global Mammal Assessment Program, Department of Biology and Biotechnologies, Sapienza University of Rome, Italy
[23] Univ Montpellier, IRD, IFREMER, CNRS, MARBEC, Montpellier, France
[24] Stanford Center for Ocean Solutions, Stanford University, Stanford, CA, USA
[25] Department of Biology and Biotechnologies, Sapienza University of Rome, Italy
[26] University of Sao Paulo, Oceanographic Institute, Fisheries Ecosystems Laboratory (LabPesq), Brazil
[27] IFREMER, Unité halieutique Manche Mer du Nord Ifremer, Boulogne-sur-mer, France
[28] UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), Cambridge, UK
[29] Department of Ecosystem Studies, University of Tokyo, Japan
[30] Senckenberg Biodiversity and Climate Research Centre (BiK-F), Frankfurt, Germany
[31] Department of Physical Geography, Goethe-University, Frankfurt, Germany
[32] Global Biodiversity Information Facility Secretariat, Copenhagen Ø, Denmark
[33] I.I. Schmalhausen Institute of Zoology of National Academy of Sciences of Ukraine, Kyiv, Ukraine
[34] U.S. Geological Survey, North Central Climate Adaptation Science Center, Fort Collins, CO, USA
[35] Department of Wildlife Biology, Forestry and Forest Products Research Institute (FFPRI), Forest Research and Management Organization, Japan
[36] Natural History Museum of Argentina, Parque Centenario, Argentina
[37] Potsdam Institute for Climate Impact Research (PIK), Member of the Leibniz Association, Potsdam, Germany
[38] Institute of Environmental Sciences, Leiden University, Leiden, The Netherlands
[39] Institute for Global Environmental Strategies (IGES), Kanagawa, Japan
[40] School of Public Policy and Global Affairs, University of British Columbia, Vancouver, Canada
[41] Rothamsted Research, Harpenden, UK
[42] School of Natural Sciences, Bangor University, Bangor, UK
[43] CIBIO (Research Centre in Biodiversity and Genetic Resources)–InBIO (Research Network in Biodiversity and Evolutionary Biology), Universidade do Porto, Vairão, Portugal

Abstract

The expert group on scenarios and models of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services initiated the development of the Nature Futures Framework for developing scenarios of positive futures for nature, to help inform assessments of policy options. This new scenarios and modelling Framework seeks to open up diversity and plurality of perspectives by differentiating three main value perspectives on nature – Nature for Nature (intrinsic values of nature), Nature for Society (instrumental values) and Nature as Culture (relational values). This paper describes how the Nature Futures Framework can be applied in modelling to support policy processes by identifying key interventions for change in realizing a diversity of desirable futures. First, the paper introduces and elaborates on key building blocks of the framework for developing qualitative scenarios and translating them into quantitative scenarios: i) multiple value perspectives on nature and the Nature Futures frontier representing diverse preferences, ii) incorporating mutual and key feedbacks of social-ecological systems in Nature Futures scenarios, and iii) indicators describing the evolution of social-ecological systems with complementary knowledge and data. This paper then presents three possible application approaches to modelling Nature Futures scenarios to support the i) review, ii) implementation and iii) design phases of policy processes. The main objective of this paper is to facilitate the integration of the relational values of nature in models, through improved indicators and other forms of evidence, and to strengthen modelled linkages across biodiversity, ecosystems, nature's contributions to people, and quality of life to identify science- and knowledge-based interventions and to enhance ecological understanding for achieving sustainable futures. The paper aims at stimulating the development of new scenarios and models based on this new framework by a wide community of modelers, and the testing and possible further development of the framework, particularly in the context of future IPBES assessments.

Keywords: scenario analysis, biodiversity, conservation, restoration, sustainable use, values, tradition, futures

1. Introduction

The Global Assessment of Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) found that human actions have altered three-quarters of the land and freshwater environment, at least 50% intensely so[1] with mostly negative impacts on biodiversity and ecosystem services. Humans also have had negative impacts on two-thirds of the marine environment over the last three decades, and continue to do so[2]. It also highlighted 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 in many parts of the world into the future[3]. This comes with potentially large socio-economic consequences[4] and inequitable impacts borne by poorer countries[5].

The drivers of biodiversity loss and other environmental degradation are rooted in population growth and inequality[6], unsustainable production and consumption patterns[7], provision of environmentally harmful subsidies[8], poor governance regimes and limited recognition of the importance of biodiversity conservation[9], and the strong reliance on fossil fuels[10] among others. To effectively address these negative drivers of change and to increase the willingness to enhance biodiversity conservation policies, societal transformations at all levels and across sectors are needed concurrently and synergistically[11]. Furthermore, revitalizing the relationship between humans and nature is fundamental in increasing priority for sustainability issues, in particular, but not exclusively, in developed countries[12], with a growing share of responsibility on remote biodiversity and habitat loss from natural resource exploitation[13], international trade[14] or the degradation of ecosystem capacity to sequester carbon[15]. Societal transformations require changes in norms and beliefs that result in behavioural changes[16], aided by effective governance[17], financial instruments[18], as well as individual champions who inspire collective action[12]. Most importantly, optimism and empathy can contribute to responsible actions[19,20] if users and actors see that they can make a difference[21] and when the process proactively engages the imagination of transformative futures[22].

Scenarios that incorporate societal transformation can contribute to reverting negative biodiversity trends and move towards positive futures[2,23,24]. However, decades of structuring global futures into a handful of scenarios (e.g., globalization, regional rivalry, economic growth) with only one or two ‘sustainability’ options have resulted in critical gaps in implementation support for conservation[25,26] and notably in identifying actionable interventions that enable transformative change through diverse stakeholders[27]. To overcome dystopian futures of collapse, transformative actions need to be informed with narratives that offer solution pathways towards more desirable futures[28]. Here, drawing on the rich plurality of value perspectives on relationships to nature from diverse places and backgrounds is key to improved decision-making[29], ensuring equitable access to benefits from nature and sharing remote responsibilities for restoring nature[5,15].

To address these, 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 wellbeing and sustainability[30]. A series of visioning consultations took place with stakeholders and experts from diverse disciplinary and sectoral backgrounds, and as a result, the Nature Futures Framework emerged for nature-centred, diverse values-reflected, and multi-scale scenarios[31,32]. The Nature Futures Framework is a heuristic tool for developing positive scenarios for nature and people by embracing multiple value perspectives people place on nature. Previous papers have developed the overall concept[30] and presented the participatory visioning exercise[31] that led to the identification of the three Nature Futures value perspectives[33]: Nature for Nature (aligned with intrinsic and existence values of nature), Nature for Society (aligned with direct and indirect use values of nature), and Nature as Culture (aligned with relational values of nature). This new scenarios and modelling framework provides entry points to the articulation and exploration of diverse future scenarios and opens up for plurality in their development and assessment.

In this paper, we reflect on how the Nature Futures Framework can be applied in modelling Nature Futures scenarios to inform policy. First, we present three key building blocks of the Nature Futures Framework for developing qualitative scenarios and translating them into quantitative modelling. We then describe three types of applications in modelling Nature Futures scenarios in policy processes. We discuss how the Nature Futures Framework may further enhance the utility of scenarios and modelling in the implementation of multiscale global policy frameworks such the Post-2020 Global Biodiversity Framework (GBF) of the Convention on Biological Diversity (CBD) and the Sustainable Development Goals (SDG) agenda with key challenges to be overcome. This paper is a synthesis of a series of workshops organized by the IPBES expert group, replaced in 2019, by the IPBES task force, on scenarios and models. The paper aims to provide useful guidance on the Nature Futures Framework to inspire the broader community to continue applying the Framework in developing scenarios and in modelling them. The ninth session of the IPBES Plenary (2022) will receive information from the task force about the Nature Futures Framework and feedback on its use and will provide guidance on further work of IPBES related to the Framework.

2. Key building blocks of the Nature Futures Framework

This section presents three key building blocks in developing Nature Futures scenarios using the Nature Futures Framework. The first building block is about how Nature Futures represent multiple value perspectives and what is the frontier in the state and policy space of social-ecological systems representing these preferences. The second building block is about how to incorporate feedbacks of social-ecological systems in Nature Futures scenarios. The third building block discusses indicators that can represent the evolution of social-ecological systems which are relevant to explore different Nature Future scenarios and their historical dynamics. The order of building blocks presented in this section does not prescribe the sequences of their application.

2.1 Nature Futures value perspectives and the frontier

Individuals and societies value nature in diverse ways[34]. Such values or preferences for nature can be represented in a multi-dimensional space, with each dimension representing one type of preferences or values[32,35]. The Nature Futures Framework attempts to capture this multi-dimensional space into three main value perspectives. Conceptually speaking, they can be seen as a projection of the multi-dimensional space into three main components or axes (Figure 1). These three key perspectives for the values of nature were identified through stakeholder consultations[31] and are aligned with the IPBES guidance on values of nature and nature's contributions to people[36]. The Nature for Nature perspective appreciates nature for what it is, as in preserving space for nature, and maps to intrinsic values and existence values of biodiversity (e.g., maintaining natural processes and structures, such as evolution, disturbance regimes, and migration). The Nature for Society perspective focuses on instrumental values as in benefits nature provides to people (e.g. supporting crop production, climate mitigation, disaster resilience)[36–38]. Finally, the Nature as Culture perspective values the relations that nature and people co-create, not as separate entities, but as an indivisible whole – reciprocal stewardship and living in harmony with nature are core characteristics (e.g., preservation of culturally-important species, sacred landscapes, and traditional knowledge)[36,37,39].

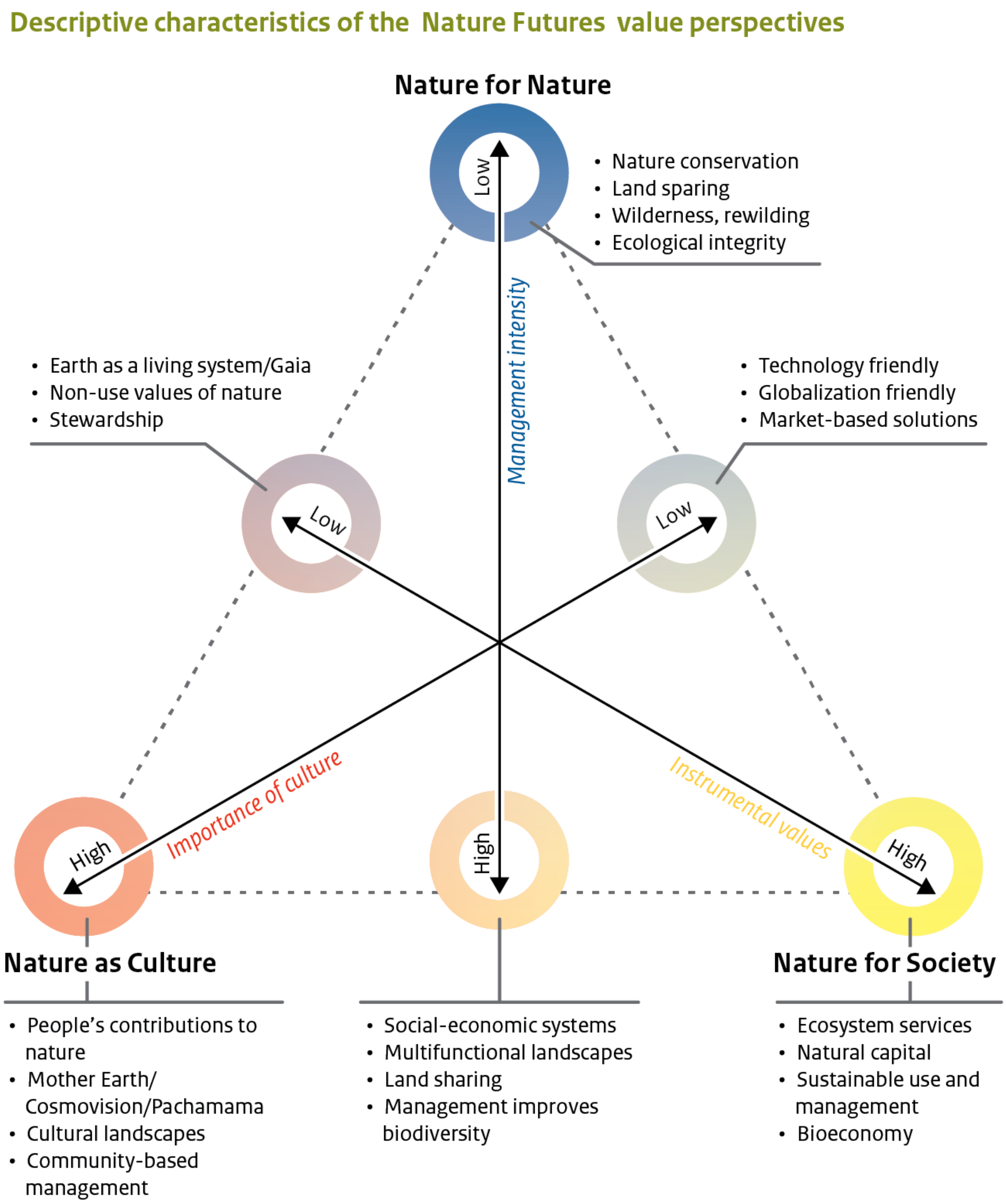


Figure 1. Descriptive characteristics of the Nature Future value perspectives and the space between these perspectives. Most systems and places in the world would have a mix of these values and map somewhere inside the triangle of the Nature Futures Framework.

The state of a social-ecological system can be plotted into the multidimensional state space by evaluating the system for each of these dimensions (Figure 2a). In this way, one can represent both the historical trajectory of a system from past to present and future pathways towards desirable end points in this state space (Figure 2a). Typically, desirable Nature Futures correspond to points of the state space where there is an improvement in all three value perspectives relative to the present. We can also assess particular actions or policies, which may move the system towards different points of the state space. For instance, we can score the relative contribution of a given action or policy towards the different axes representing different value perspectives, to produce a policy space of Nature Futures (Figure 2b).

Important to point out, however, is that many interventions can be appropriate and even necessary under more than one nature value perspective. For example, there are different categories of protection in protected areas – they can strictly limit human access, allow access for recreation or be placed in indigenous peoples' land – all of which have mixed representation of perspectives with different short to long term co-benefits and trade-offs. Furthermore, the pathways from the past to the present can inform the pathways to the futures based on observed evidence of co-benefits and trade-offs across the interventions, with different degrees of alignment with nature value perspectives. Integrating positive and mutually reinforcing feedbacks of these nature value perspectives in models will be a novel challenge for developing Nature Futures scenarios, acknowledging that trade-offs between perspectives can be difficult to measure if values are fundamentally different, immeasurable and incomparable[40].

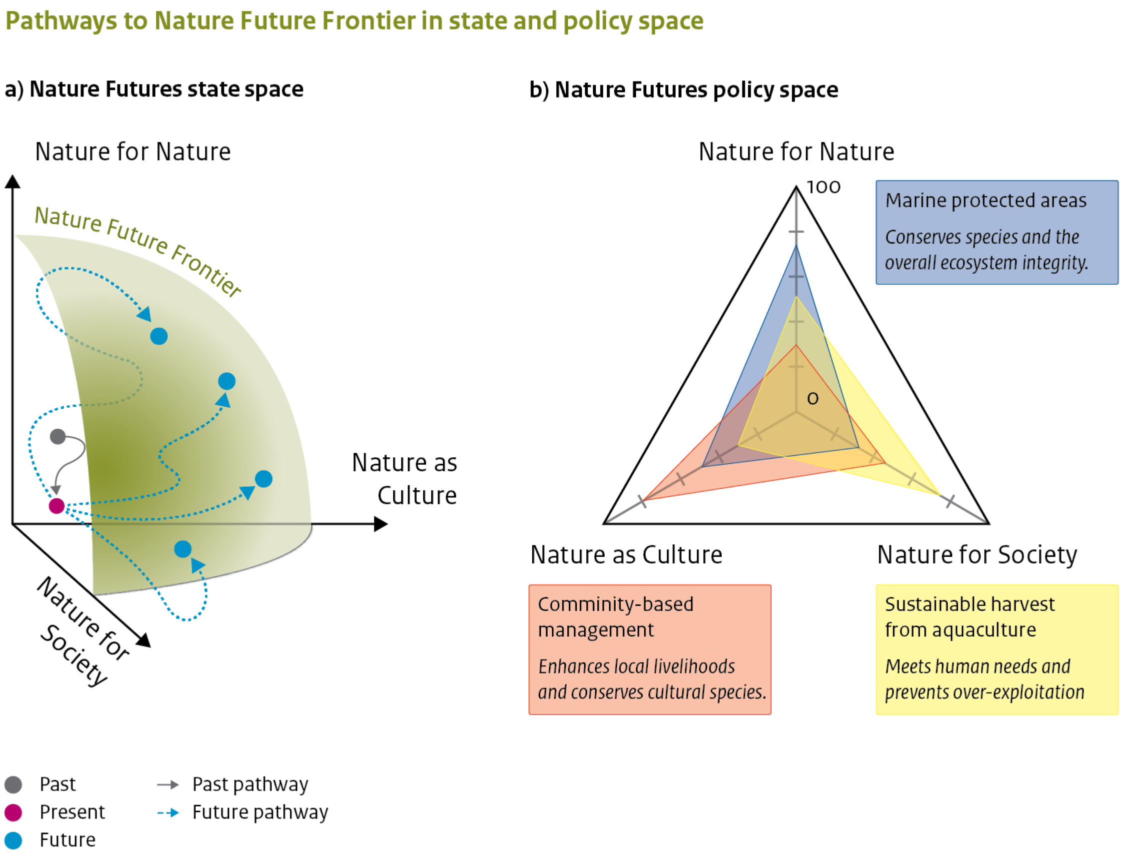


Figure 2. (a) Nature Futures state space and frontier (green concave with blue dots) with multiple pathways to desirable futures where all three value perspectives improve relatively to present. (b) Nature Futures policy space with interventions and indicators scored and mapped across value perspectives for a point in time or as a progress over two time points, illustrated with example policies (blue yellow and orange triangles).

The three Nature Future value perspectives on nature, however, are not mutually exclusive – in fact, they are intricately connected and can mutually reinforce each other[41]. Keystone species are such an example with their functional role benefiting both nature and society (e.g., top predators control herbivore populations and reduce damage to crops[42], animal movements mediate carbon exchange between ecosystems and the atmosphere)[42,43]. Therefore, although we represent the state space of social-ecological systems with these three axes as orthogonal for simplicity (Figure 2a), a more precise representation would have these three axes as partially overlapping, as some of the values overlap across the three perspectives. That is, an increase of the values along one axis of the three value perspectives can per se correspond to an increase along another axis. Still, it is important to recognize that in some parts of the state space there may be trade-offs between improvements in the three axes, corresponding effectively to a frontier in the state space (Figure 2a): when the values of a given axis are already very high, further improvements along that axis may only be achievable by decreasing the values along another axis. We do not know the shape of this frontier, but we represent it as a concave 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.

Furthermore, one can explore more extreme or distinct value perspectives in the state space at smaller spatial scales than at larger spatial scales. This is, one can envision a world where different locations are managed exclusively for one of the value perspectives, but at the regional and certainly at the global scale, all three value perspectives must co-exist given diversity. In addition, one can envision futures where all perspectives co-exist in all locations or alternatively a world where there is some spatial segregation of the perspectives. That is, if one was to plot each location in the world in the state space, a cloud of points could cluster towards the center or disperse across all the corners of the frontier.

2.2 Social-ecological systems with feedbacks

Feedbacks between people and nature are at the centre of the IPBES conceptual framework[44]. Understanding interactions and feedbacks is essential for understanding what types of nonlinear dynamics can occur either towards or away from positive futures. However, only some of the social-ecological feedbacks present in the IPBES conceptual framework are captured in existing environmental models (Figure 3)[27,30,45–47]. Nature Futures scenarios should integrate key social-ecological feedbacks identified through historical and forecasting analyses[48,49]. Such analyses should include diverse geographic locations and settings since key feedbacks are likely to vary across different regions[50].

Interventions aimed at improvements in one value perspective can result in social-ecological dynamics that lead to improvements in another value perspective or even trigger interventions across other perspectives. For instance, interventions targeted at improving the state of ecosystems through biodiversity protection (predominantly representing Nature for Nature) can lead to sustainable provision of ecosystem functions and services (Nature for Society)[51] as well as securing space and rights for maintaining culture (Nature as Culture)[52]. Similarly, securing land ownership for and management by indigenous and local communities (predominantly representing Nature as Culture) can contribute to maintaining intact habitats to conserve biodiversity (Nature for Nature) with long-standing local knowledge of that region, thereby ensuring benefits to society from sustainable livelihood sources

(Nature for Society) through healthy ecosystems[53,54]. Thus, assessing which interventions are particularly relevant for a specific (or combination of) nature value perspectives are particularly important for understanding where multiple values are present and reinforce each other.

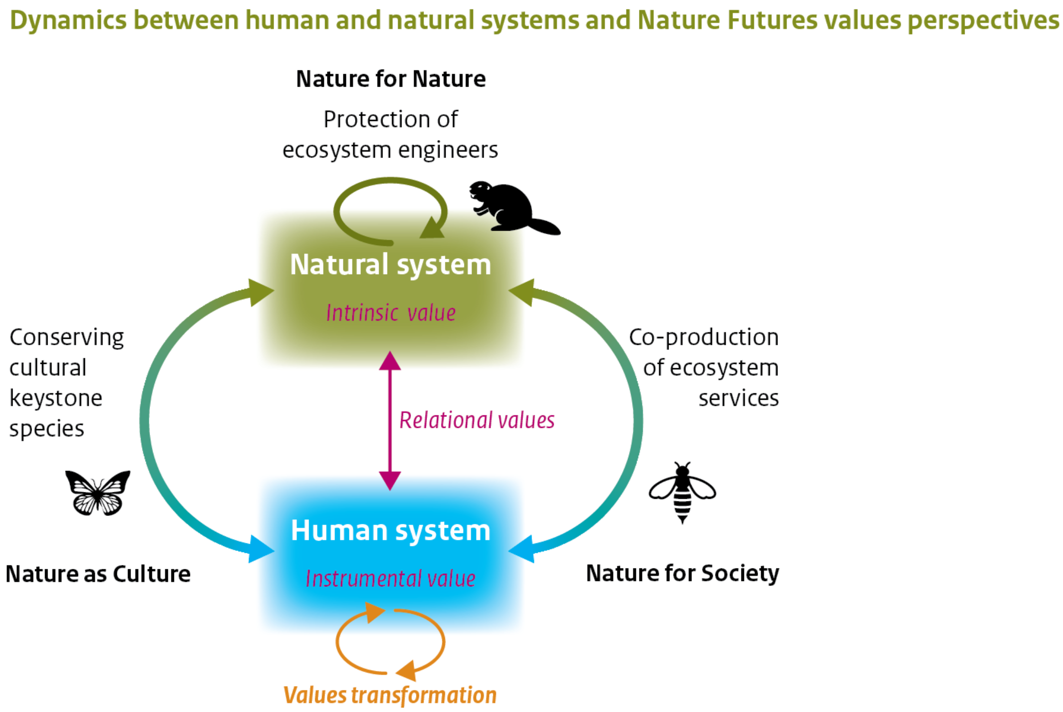


Figure 3. Dynamics between human and natural systems represented by a simple model with feedback loops within and between the systems that reflect Nature Futures value perspectives.

Different types of feedback dynamics are important for each of the value perspectives in the Nature Futures Framework, but they are not equally well represented in existing models. To date, most modelling approaches have adopted Nature for Nature and Nature for Society perspectives[55], and therefore feedbacks that are important for these value perspectives are sometimes represented, however only partially for services other than food provision or only with a limited representation of the natural system. For example, many models represent agricultural land conversion in which crop production interacts with demand for crop production to drive land use change[56,57] and in some cases, changes in the production feedback to changes in human-well being. But we lack models representing how some interventions such as land-use change result in changes in regulating ecosystem services, and this may in turn, affect societal decisions so that land-use change processes are altered. The Nature for Nature perspective is represented in ecological models, some of which capture ecological feedback processes, such as fire dynamics[58], but such feedbacks are often missing from large scale environmental models and disconnected from social dynamics. As an example, the role of keystone species in shaping ecosystems is a key feature that is seldom captured in models, such as how beavers create wetlands and landscape heterogeneity by felling trees and blocking water flows[59].

Feedbacks that is important for the Nature as Culture perspective is the least understood and modelled. For example, cultural keystone species[60], 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 for the community. However, we are not aware of any models of the social-ecological feedbacks around cultural keystone species. There are initiatives enhancing a structured understanding of feedbacks between components in social-ecological systems[49,61] with examples of participatory scenarios that integrate social-ecological systems with limitations in application at one scale or level of the system[26]. In general, coupled social-ecological modelling is still in its infancy and requires further development[62,63].

2.3 Indicators of knowledge and data as multiple evidence bases

In going from the narratives (descriptive storylines about the future visions and pathways) of Nature Futures scenarios to decision support in policy processes, indicators derived from models, data, and diverse knowledge systems can build an integrative multiple evidence base for decision-making[64–66]. Indicators can be used to describe and measure the status, trend, and magnitude of relationships between components of key social-ecological systems, and to identify models, variables and data required in dialogue and consultation with stakeholders[67,68] (Table 1). Methods such as mental mapping, decision tree and multiple objective optimization can be utilized to select key indicators and variables to be modelled in Nature Futures scenarios[69,70]. To ensure the inclusion of diverse perspectives and preferences on nature, indicators are ideally co-determined and co-developed with stakeholders and users of information[71,72].

Using both the IPBES conceptual framework and the Nature Futures Framework, interventions can be selected on a range of direct (anthropogenic, natural) and indirect (institution, governance, anthropogenic assets) drivers for exploration and assessment of their impacts against goals set on nature, nature's contributions to people and quality of life (Table 1, Figure 4). Interventions and goals can be cross-cutting, for instance, promoting national and international systems and cooperation on biodiversity and sustainability (indirect drivers of institutions and governance), supporting community learning facilities that enhance public awareness on activities on conservation and sustainability issues (anthropogenic asset), and preventing species from extinction (nature) and ecosystems from degradation (nature's contributions to people) – or they can have a "home" in one of the value perspectives, as demonstrated in the policy space (Figure 2b). As an example, agro-environmental measures as an intervention on governance can be targeting high production on most fertile lands to allow space for nature while avoiding high biodiverse areas (Nature for Nature), or maximize co-production of ecosystem services to provide sufficient food for all people (Nature for Society), or support environmentally friendly smallholder production in cultural landscapes for local consumption (Nature as Culture). Furthermore, life satisfaction as a goal on quality of life can be measured from the enjoyment of experiencing nature and knowing that other species are being protected (Nature for Nature), from various types of quality goods and services from nature and knowing that they are equitably shared (Nature for Society) or from preserving nature-based cultural heritage and intergenerational social cohesion (Nature as Culture).

A wide range of indicators can be used to assess the status of interventions put in place and the progress made on goals for each component of the IPBES conceptual framework across the Nature Future value perspective (Table 1). Indicators representing diverse facets, roles and benefits of nature would provide rich insights and evidence required for modelling social-ecological systems dynamics and allow for more comprehensive analyses, optimization, and prioritization[24,73–75]. Furthermore, science and data-based reference levels in indicators can contribute significantly to setting policy targets[76] and measuring impacts[77], accumulating conservation and sustainability evidence to inform future decisions[78].

Table 1. Illustrative features of the Nature Future value perspectives with example indicators from existing sources or aspirational ones. The components of the IPBES conceptual framework are used to identify the interventions and goals (rows) across the three Nature Futures value perspectives and those that are cross-cutting (columns).

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., CBD, SDG. Number of countries that have reported legislative, administrative and policy frameworks or measures to implement international environmental treaties)*	Giving legal rights to nature and adequate management capacity to protect nature *(e.g., LIT. number of countries/municipalities that have assigned rights to nature in their constitutions)*	Developing environmentally friendly infrastructure for human settlement *(e.g., SDG 7.b.1. Investments in energy efficiency as a proportion of GDP and the amount of foreign direct investment in financial transfer for infrastructure and technology to sustainable development services)*	Including indigenous and local knowledge on nature in education curriculum *(e.g., LIT. number of countries/municipalities that have education curriculum on indigenous and local knowledge on nature)*
	Implementing agro-environmental measures not perverse to nature conservation and human wellbeing *(e.g., indicator/index measuring the overall impact of agro-environmental measures on nature and people)*	Implementing agro-environmental measures targeting high production on most fertile lands, avoiding biodiverse areas, to spare space for nature *(e.g., % agro-environmental measures allocated to fertile lands and their productivity level)*	Implementing agro-environmental measures targeting maximum co-production of ecosystem services *(e.g., % agro-environmental measures allocated to maximize co-production of ecosystem services)*	Implementing agro-environmental measures targeting environmentally friendly smallholder production in cultural landscapes for local consumption *(e.g., % agro-environmental measures allocated to smallholder production in cultural landscape for local consumption)*
- Anthropogenic assets	Community learning facilities that enhance public awareness and activities on conservation and sustainability issues *(e.g., number of public events on conservation and sustainability topics)*	Creating protection, management and education facilities for wildlife watching *(e.g., number of wildlife watching facilities by protection level, management type, and educational programs)*	Engaging the private sector to deploy nature-based solutions that benefit both nature and people *(e.g., amount of investment of private firms deploying nature-based solutions)*	Establishing community associations for supporting local production and consumption and fair trade *(e.g., INI D2. Trends in consumption of diverse locally-produced food)*
Interventions on direct drivers - Anthropogenic and natural	Designating different types of protected areas *(e.g., CBD AT 11. % of area covered by protected areas by type – marine, coastal, terrestrial, inland water)*	Rewilding of abandoned and degraded land to improve biodiversity, e.g. introduction of large herbivores Reforestation to protect watershed and mangrove areas	Applying nature-based solutions to mitigate climate impact, e.g. afforestation, urban parks, renewable energy like solar and wind power *(e.g., % contribution of NBS to climate change mitigation by type)*	Community based management (CBM) of natural resources, e.g. other effective area-based conservation measures (OECMs) where wild crop relatives grow

		(e.g., % of total land being rewilded, reforested and restored)		*(e.g., % of total land with wild crop relatives by management type)*
Goals on nature - Biodiversity and ecosystems	Preventing species from extinction *(e.g., CBD AT12 Species Protection Index, number of species prevented from extinction)*	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. trends in natural ecosystem extent, 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 2.5.2 % of undernourished people* *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 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 L1. Possibility to perform traditional occupations (such as pastoralism, hunting/gathering, shifting cultivation, fishing) without restriction as a proxy)*

*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 for that value perspective.
*Sources: CBD AT: Convention on Biological Diversity Aichi Target, SDG: Sustainable Development Goals, INI: Indigenous Navigator Indicator, LIT: literature

3. Modelling Nature Futures scenarios to inform policy processes

In this section, we present three possible modelling applications of Nature Futures scenarios for supporting policy processes (Table 2). The three applications we present here are not examples of existing Nature Futures scenarios nor a protocol for developing such scenarios. Instead, they present the kind of issues that need to be addressed in Nature Futures scenarios for three different phases of the policy development cycle[79]: policy review, policy screening and policy design. We discuss the types of objectives, policy questions and tools, models, and modelling challenges that are associated with each application approach at different spatial scales.

Table 2. Summary of the three modelling application approaches of the Nature Futures Framework to inform policy processes.

	Application 1. Policy review *(ex-post)*	**Application 2. Policy screening** *(ex-ante)*	**Application 3. Policy design and agenda setting** *(ex-ante)*
Objectives	Evaluates 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 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 protected areas feedback to societal decisions)?
Policy tool examples	CBD National Reports	CBD Local and National Biodiversity Strategy and Action Plans	CBD Post-2020 Global Biodiversity Framework
Modelling approaches	Emphasizes past observations. Counterfactual 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 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, questions and tools for modelling applications in policy processes

The Nature Futures Framework can be used in exploring a much broader array of interventions, compared to previous environmental scenarios, to inform local, national and global goals of policy frameworks (e.g., CBD National Biodiversity Strategy and Action Plans, CBD National Reports, CBD Post-2020 Global Biodiversity Framework). The Nature Futures Framework can be applied retrospectively to evaluate the performance of past policies and interventions (policy review), assess potential consequences of particular policy and management options (policy screening) or identify broader goals for policy-making (policy design and agenda setting) on nature and people (Table 2).

For policy review, counterfactual analysis of direct drivers on biodiversity and nature's contributions to people can inform what the trends of biodiversity have been where particular policies were implemented (e.g., different types of protected areas) and what has happened in places where such measures have not been implemented[80,81]. There has been an increasing use of synthesis methods such as systematic review[78,82–84], meta analyses[85] and impact assessment employing counterfactuals using econometric and statistical techniques such as matching[81,86–88] and before-after control impact (BACI)[89,90]. Models of direct drivers and their impacts on biodiversity can also be used to fill spatial and temporal gaps in historical data and are key to assess impacts on ecosystem services[91].

For policy screening, models can be used to predict the consequences for different policy decisions affecting particularly direct drivers (e.g., location and types of protected areas) on biodiversity, ecosystem services and quality of life (Figure 4). For these relatively short-term analyses (e.g., one decade), modelling the full dynamics of indirect drivers and closing the social-ecological feedback loops are not always necessary or feasible, although can be useful, particularly at more local scales.

For policy design and agenda setting, a broader set of social-ecological models can be used to identify societal transformations needed in achieving long-term visions, integrating effects of changes in nature's contributions to people in future societal decisions (e.g., how do benefits of protected areas inform societal changes and decisions in turn). Here, both the modelling of the interventions on indirect drivers and their dynamics and closing social-ecological feedback loops are essential in developing robust scenarios (Figure 3).

3.2 Scenario analysis in state space and policy space

In scenarios analyses using the Nature Futures Framework for policy support, a single policy can be scored and mapped in the Nature Futures policy space to assess how the system is likely to evolve along the three perspectives (Figure 2b). Although most policies will have an impact on the state of the system on the three nature value perspectives, some policies may favor particularly one perspective. Assigning interventions to different nature value perspectives allows us to evaluate the consequences of different preferences and priorities that are latent in decision options.

A combination of policies can be tested in a modelling framework to analyze the most important levers to move the state of the system towards improved states along the three Nature Futures axes in the state space, and eventually towards the Nature Futures frontier (Figure 2a). For example, marine protected areas (to conserve species and overall ecosystem integrity), community-based management (to enhance local livelihood and to conserve cultural species) and sustainable harvest from aquaculture (to meet human needs and to minimize over-exploitation) can be assessed individually in the policy space (Figure 2b) or together in an integrated manner in the state space (Figure 2a). In addition, the temporal trajectory of the system can only be assessed in state space. To use the Nature Futures state space as output of modelling scenarios beyond concepts, it is important to use multiple variables and indicators to assess the state of the system (Table 1, Figure 4). This means, to represent evolution of the system quantitatively in a three-dimensional state space, with a single score per axis, some projection of those indicators into the three Nature Futures axes needs to occur first. For instance, the overall score along the Nature for Nature axis can be calculated by averaging all indicators on the state of nature, nature contributions to people and quality of life that are deemed to be associated with that axis.

3.3 Key remaining research challenges to model the Nature Futures scenarios

Most modelling approaches have not yet incorporated a structured way of representing multiple values of nature or only do so in a limited fashion[92]. This is particularly true for the relational values of nature. Integrating diverse value perspectives in modelling is important for a more comprehensive assessment of the consequences of value-reflected decisions on nature and people. The Nature Futures Framework brings these multiple values to the forefront of scenario development and provides guidance on how they can be incorporated in modelling by exploring indicators relevant for each of the perspectives (Table 1, Figure 4).

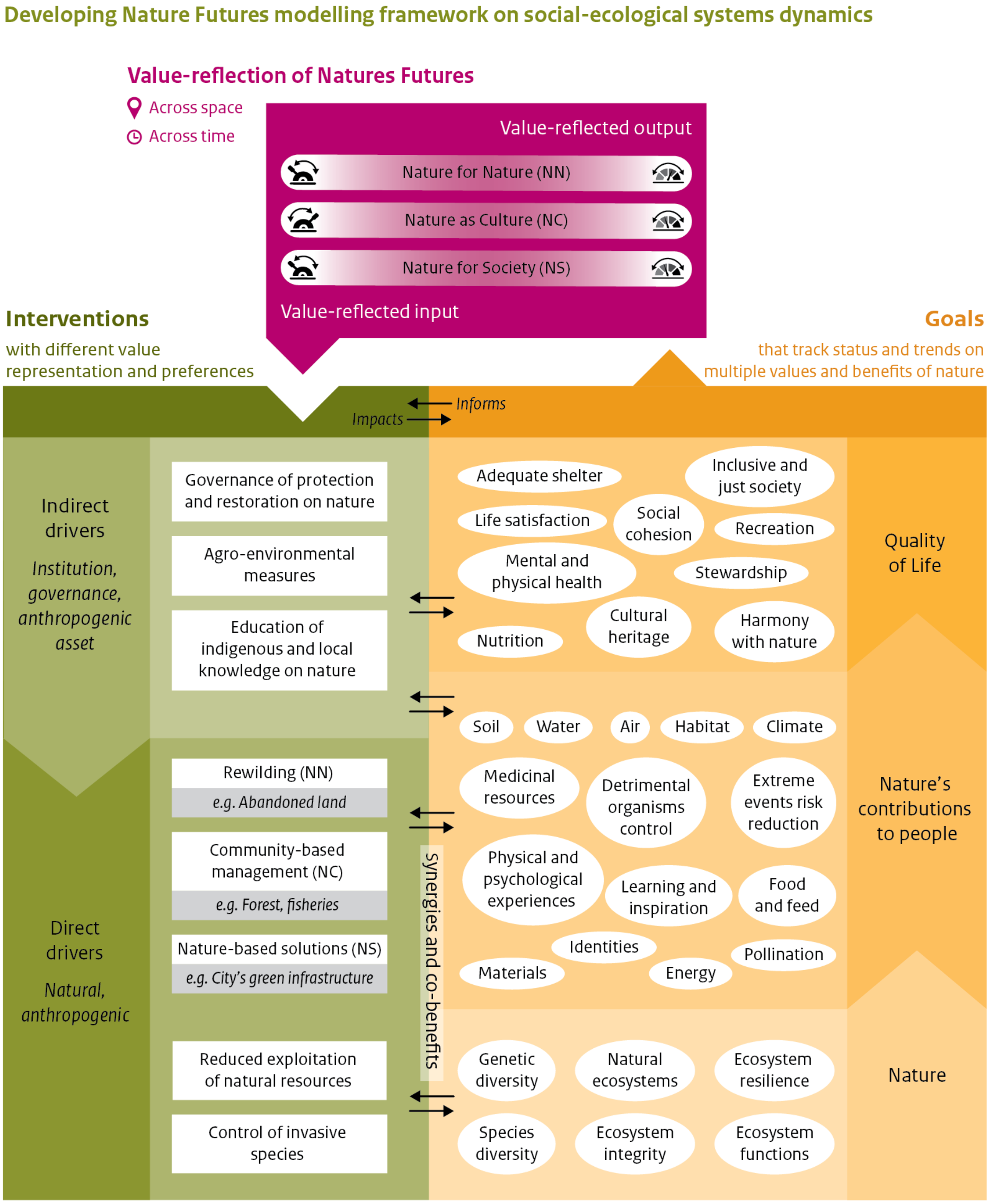


Figure 4. An illustrative modelling framework on sustainable sea and land use using components of the IPBES conceptual framework with interventions on indirect and direct drivers (left panel) and goals on nature, nature's contributions to people and quality of life (right panel). The Nature Futures scenarios can combine different degrees of nature values to assess the consequences of value reflected interventions (input) on nature and people (output). A few illustrative interventions on direct drivers are rewilding (e.g., abandoned land) primarily, however not exclusively, for Nature for Nature, community-based management (e.g., forest and fisheries) for Nature as Culture and nature-based solution (e.g., green infrastructure) for Nature for Society as value reflected input into modelling, further supported by indirect drivers such as governance, subsidies and education. The state of nature, nature's contributions to people, and quality of life can be measured using multiple indicators to represent diverse values and benefits. The Nature Futures scenarios places emphasis on identifying synergistic interventions with co-benefits across drivers and their impacts on nature and people.

Integrating time series monitoring data in models of the impacts of direct drivers on biodiversity and ecosystem services remains a key challenge[45]. Most existing biodiversity models use some type of space for time replacement in the calibration of models. This issue is particularly relevant for retrospective policy evaluation where time series data are required to estimate impacts for evidence-based forecasting.

An increasing suite of models, variables and indicators are being made available for more comprehensive, complementary and potentially rigorous assessments on biodiversity and nature's contributions to people[5,24,93,94]. However, a broader set of drivers needs to be represented in impact models to allow for the screening of a wider range of positive policy interventions which are called for by the Nature Futures scenarios[95,96].

Finally, new models are in development that aim to directly incorporate feedbacks that reflect the effect of biodiversity and ecosystem services provision factors on economy and vice versa[97,98], which has been missing in environmental and sustainability scenarios. Long term social-ecological feedbacks at large scales, and incorporation of tipping points/regime shift need to be fully considered to optimize the efficacy of Nature Futures scenarios in policy design[30,99].

As with any type of modelling, there will be multiple types of uncertainties associated with Nature Futures scenarios, including the models and methodologies chosen, their structures, parameters, assumptions, as well as inherent uncertainties in co-developed scenarios and in their implementation[46,100–102]. There will also be epistemological and ontological differences across sectors, disciplines and cultures that will need to be discussed throughout the scenarios and modelling process[103]. A systematic exploration of uncertainties in models of biodiversity and ecosystem services as well as those connected in atmospheric, biophysical, social and political domains will be necessary[104]. To address these challenges, standard definitions, protocols on ensemble modelling, and further guidance on the application of Nature Futures Framework will lead to more consistent scenarios and modelling practices. Finally, uncertainties associated with scenarios and modeling should be communicated clearly as limitations to the users of Nature Futures end-products[47].

4. Moving towards Nature Futures

To date, scenarios and models in environmental assessments have tended to focus on representing human impacts on ecosystems[27,105]. Scenarios and models can integrate a broad set of the world's dynamics, as well as potential conflicts and synergies among different value perspectives by including components and processes that represent diverse value perspectives that matter to people and nature[31]. To achieve this, the existing models on biodiversity, ecosystem services and social-ecological systems could be coupled to form a comprehensive framework that integrates potential feedbacks across them, thereby improving the representation of globally connected social–ecological systems that exhibit complex cross-scale interactions[63]. Furthermore, modelling needs advancement in linking across biodiversity, ecosystems, nature's contributions to people, and quality of life to rigorously identify science- and knowledge-based interventions and to enhance ecological understanding for achieving sustainable futures[106,107]. In catalyzing the development of Nature Futures scenarios, capacity needs to be developed in modelling how environmental change alters human behaviour, institutions, or culture and vice versa[62,108]. In addition, relational values of nature need to be better reflected in models and indicators, and may need to be supplemented by other forms of evidence. Modelling the social-ecological systems dynamics connecting the regional scale would also be a novel challenge for Nature Futures scenarios given its limited development at a broader scale despite its relevance for conservation and sustainability.

Model algorithms developed based on observed data are key to rigorously predict changes into the future[109,110], enhancing the credibility of models for the use of scenario-based information in policy processes. A wide range of observation data (socio-economic, environmental, management) and correlation with observed trends in drivers can be used to forecast responses of biodiversity and ecosystems under different policy interventions, although extrapolation based on empirical relationships is expected to apply only for relatively short time periods. The increasing availability of high-resolution remote-sensing and other widely varying observational evidence ("big data"), jointly with advanced machine learning technologies and cloud-based computing, can all contribute significantly to increasing the predictive power of changes in biodiversity and its contributions to people[111–113]. Making Nature Futures scenarios truly biodiversity-centric thus represents a critical challenge in biodiversity science that is now being tasked to shift the conventional impact modelling of negative anthropogenic drivers on environment to positive anthropogenic drivers and impacts of biodiversity informing how people and societies can prosper with nature.

As elaborated in this paper, the Nature Futures Framework aims to support transformative change towards sustainable futures by placing human-nature relationships at the center through co-creating future visions. It bridges across knowledge systems and communities of practices through continuous dialogue, thereby integrating multiple evidence sources while maintaining a minimum consistency and comparability in scenarios and models[114]. In the coming years, we expect that the Nature Futures approach to participatory scenarios and modelling will enable scientific and stakeholder communities to identify policy and management interventions that incorporate diverse nature values. To achieve this, an inclusive approach is being followed around the Nature Futures Framework, which engages diverse stakeholders in developing narratives, engineering of models and building a multiple evidence base to better assess conservation and sustainability issues and solutions that matter and can work for the future of nature and people[31,96,99]. This inclusive participatory approach is meant to ensure that the information generated from the models and other knowledge systems is relevant to the stakeholders involved and thus used by them to initiate and amplify societal transformation. This work is also expected to contribute to the IPBES "transformative change assessment", which the member states of IPBES initiated at its eighth Plenary session in June 2021. Addressing interlinkages, co-benefits and trade-offs between sectors, such as food, biodiversity, water and energy with so-called nexus approaches, will be crucial to develop pathways for achieving multiple global goals[115,116]. For this, we need cross-sectoral scenario analyses that include models that matter for biodiversity and ecosystem services, developed through collaboration with intergovernmental institutions, scientific communities, civil societies, data custodians, local communities, and citizens. The work produced will contribute to the IPBES "nexus assessment", which was also 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 and support the efforts of scientists and other knowledge holders to better link societal transformations to individual and societal values and associated decisions. In an era where combined global environmental changes are at play (e.g., climate change, habitat destruction, pollutions), marine, terrestrial and freshwater biodiversity is imperilled. The spread of COVID-19 has already transformed social-ecological systems, pressing new norms on all societies and bringing a sense of extreme urgency to the identification of new pathways towards futures where both nature and people can thrive together. The Nature Future Framework presented in this paper is expected to stimulate the development of scenarios and models that inform the achievement of goals in multiscale global policy frameworks such as the CBD Post-2020 Global Biodiversity Framework and The Sustainable Development Agenda.

Glossary

Co-benefits: It refer 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'[10,117].

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)[79].

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[10]

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[118].

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"[30].

Nature Futures Framework (NFF)[33]**:** A heuristic that captures diverse, positive values for human-nature relationships in a triangular space.

Nature Futures value perspectives[31]: 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[119,120]. The Three Horizons approach is often used to define such pathways in future visioning processes[121].

Policy space: Nature Futures policy space utilizes interventions and 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[122]. However, to improve the evidence base for policy decisions, retrospective evaluation is critical in informing the design and implementation of policies[81,123,124].

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)"[125].

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"[28,126]. "Seeds" are innovative initiatives, practices and ideas that are present in the world today, but are not currently widespread or dominant[28,32].

References

1. Arneth, A. *et al.* 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* (2019).

2. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. *Summary for policymakers of the global assessment report on biodiversity and ecosystem services*. (2019).

3. Pereira, H. M. *et al. Global trends in biodiversity and ecosystem services from 1900 to 2050*. http://biorxiv.org/lookup/doi/10.1101/2020.04.14.031716 (2020) doi:10.1101/2020.04.14.031716.

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

5. Chaplin-Kramer, R. *et al.* Global modeling of nature's contributions to people. *Science* **366**, 255–258 (2019).

6. Hamann, M. *et al.* Inequality and the Biosphere. *Annu. Rev. Environ. Resour.* **43**, 61–83 (2018).

7. Hoekstra, A. Y. & Wiedmann, T. O. Humanity's unsustainable environmental footprint. *Science* **344**, 1114–1117 (2014).

8. Dempsey, J., Martin, T. G. & Sumaila, U. R. Subsidizing extinction? *CONSERVATION LETTERS* **13**, (2020).

9. Smith, R. J., Muir, R. D. J., Walpole, M. J., Balmford, A. & Leader-Williams, N. Governance and the loss of biodiversity. *Nature* **426**, 67–70 (2003).

10. Intergovernmental Panel on Climate Change. *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, 2015).

11. Chan, K. M. A. *et al.* Levers and leverage points for pathways to sustainability. *People and Nature* **2**, 693–717 (2020).

12. Amel, E., Manning, C., Scott, B. & Koger, S. Beyond the roots of human inaction: Fostering collective effort toward ecosystem conservation. 6 (2017).

13. Swartz, W., Rashid Sumaila, U., Watson, R. & Pauly, D. Sourcing seafood for the three major markets: The EU, Japan and the USA. *Marine Policy* **34**, 1366–1373 (2010).

14. Chaudhary, A. & Kastner, T. Land use biodiversity impacts embodied in international food trade. *Global Environmental Change* **38**, 195–204 (2016).

15. Marques, A. *et al.* Increasing impacts of land use on biodiversity and carbon sequestration driven by population and economic growth. *Nat Ecol Evol* **3**, 628–637 (2019).

16. Kinzig, A. P. *et al.* Social Norms and Global Environmental Challenges: The Complex Interaction of Behaviors, Values, and Policy. *BioScience* **63**, 164–175 (2013).

17. Amano, T. *et al.* Successful conservation of global waterbird populations depends on effective governance. *Nature* **553**, 199–202 (2018).

18. Waldron, A. *et al.* Reductions in global biodiversity loss predicted from conservation spending. *Nature* **551**, 364–367 (2017).

19. Brown, K. *et al.* Empathy, place and identity interactions for sustainability. *Global Environmental Change* **56**, 11–17 (2019).

20. Tschakert, P. More-than-human solidarity and multispecies justice in the climate crisis. *Environmental Politics* 1–20 (2020) doi:10.1080/09644016.2020.1853448.

21. Knowlton, N. Earth Optimism—recapturing the positive. *Oryx* **53**, 1–2 (2019).

22. Pereira, L., Sitas, N., Ravera, F., Jimenez-Aceituno, A. & Merrie, A. Building capacities for transformative change towards sustainability: Imagination in Intergovernmental Science-Policy Scenario Processes. *Elem Sci Anth* **7**, 35 (2019).

23. Fischer, J. & Riechers, M. A leverage points perspective on sustainability. *People Nat* **1**, 115–120 (2019).

24. Leclère, D. *et al.* Bending the curve of terrestrial biodiversity needs an integrated strategy. *Nature* (2020) doi:10.1038/s41586-020-2705-y.

25. Hamann, M. *et al.* Scenarios of Good Anthropocenes in southern Africa. *Futures* **118**, 102526 (2020).

26. Sitas, N. *et al.* Exploring the usefulness of scenario archetypes in science-policy processes: experience across IPBES assessments. *E&S* **24**, art35 (2019).

27. Pereira, L. *et al.* Advancing a toolkit of diverse futures approaches for global environmental assessments. *Ecosystems and People* **17**, 191–204 (2021).

28. Bennett, E. M. *et al.* Bright spots: seeds of a good Anthropocene. *Frontiers in Ecology and the Environment* **14**, 441–448 (2016).

29. Pascual, U. *et al.* Biodiversity and the challenge of pluralism. *Nat Sustain* (2021) doi:10.1038/s41893-021-00694-7.

30. Rosa, I. M. D. *et al.* Multiscale scenarios for nature futures. *Nat Ecol Evol* **1**, 1416–1419 (2017).

31. Pereira, L. M. *et al.* Developing multiscale and integrative nature–people scenarios using the Nature Futures Framework. *People and Nature* **2**, 1172–1195 (2020).

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

33. Lundquist, C. J. *et al.* A pluralistic Nature Futures Framework for policy and action. (In preparation).

34. Harmáčková, Z. V. *et al.* Linking multiple values of nature with future impacts: value-based participatory scenario development for sustainable landscape governance. *Sustain Sci* (2021) doi:10.1007/s11625-021-00953-8.

35. PBL Netherlands Environmental Assessment Agency. *Next steps in developing Nature Futures*. (2018).

36. Pascual, U. *et al.* Valuing nature's contributions to people: the IPBES approach. *Current Opinion in Environmental Sustainability* **26–27**, 7–16 (2017).

37. Chan, K. M. A. *et al.* Opinion: Why protect nature? Rethinking values and the environment. *Proc Natl Acad Sci USA* **113**, 1462–1465 (2016).

38. O'Connor, S. & Kenter, J. O. Making intrinsic values work; integrating intrinsic values of the more-than-human world through the Life Framework of Values. *Sustain Sci* **14**, 1247–1265 (2019).

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

40. Keeney, R. L. Common Mistakes in Making Value Trade-Offs. *Operations Research* **50**, 935–945 (2002).

41. Martín-López, B. Plural valuation of nature matters for environmental sustainability and justice. *The Royal Society* (2021).

42. Martin, J., Chamaillé-Jammes, S. & Waller, D. M. Deer, wolves, and people: costs, benefits and challenges of living together. *Biol Rev* **95**, 782–801 (2020).

43. Schmitz, O. J. *et al.* Animals and the zoogeochemistry of the carbon cycle. *Science* **362**, eaar3213 (2018).

44. Díaz, S. The IPBES Conceptual Framework — connecting nature and people. *Current Opinion in Environmental Sustainability* 16 (2015).

45. Rosa, I. M. D. *et al.* Challenges in producing policy-relevant global scenarios of biodiversity and ecosystem services. *Global Ecology and Conservation* **22**, e00886 (2020).

46. Peterson, G. *et al.* Chapter 5 Modelling consequences of change in biodiversity and ecosystems for nature and nature's benefits to people. in *The methodological assessment report on scenarios and models of biodiversity and ecosystem services* (IPBES, 2016).

47. Akçakaya, H. R. *et al.* 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* (IPBES, 2016).

48. Miller, B. W., Caplow, S. C. & Leslie, P. W. Feedbacks between Conservation and Social-Ecological Systems: *Conservation and Social-Ecological Systems*. *Conservation Biology* **26**, 218–227 (2012).

49. Rocha, J., Malmborg, K., Gordon, L., Brauman, K. & DeClerck, F. Mapping social-ecological systems archetypes. *Environ. Res. Lett.* **15**, 034017 (2020).

50. Koellner, T. *et al.* Guidance for assessing interregional ecosystem service flows. *Ecological Indicators* **105**, 92–106 (2019).

51. Cardinale, B. J. *et al.* Biodiversity loss and its impact on humanity. *Nature* **486**, 59–67 (2012).

52. Stolton, S. *et al.* Values and Benefits of Protected Areas. in *Protected Area Governance and Management* (2015).

53. *Indigenous and traditional peoples and protected areas: principles, guidelines and case studies*. (IUCN-The World Conservation Union, 2000).

54. Dinerstein, E. *et al.* A "Global Safety Net" to reverse biodiversity loss and stabilize Earth's climate. *Sci. Adv.* **6**, eabb2824 (2020).

55. Robinson, D. T. *et al.* Modelling feedbacks between human and natural processes in the land system. *Earth Syst. Dynam.* **9**, 895–914 (2018).

56. Lambin, E. F. & Meyfroidt, P. Global land use change, economic globalization, and the looming land scarcity. *Proc Natl Acad Sci USA* **108**, 3465–3472 (2011).

57. Stehfest, E. *et al.* Key determinants of global land-use projections. *Nat Commun* **10**, 2166 (2019).

58. McLauchlan, K. K. *et al.* Fire as a fundamental ecological process: Research advances and frontiers. *J Ecol* **108**, 2047–2069 (2020).

59. Willby, N. J., Law, A., Levanoni, O., Foster, G. & Ecke, F. Rewilding wetlands: beaver as agents of within-habitat heterogeneity and the responses of contrasting biota. *Phil. Trans. R. Soc. B* **373**, 20170444 (2018).

60. Garibaldi, A. & Turner, N. Cultural keystone species: Implications for ecological conservation and restoration. *Ecology and Society* **9**, (2004).

61. Lauerburg, R. A. M. *et al.* Socio-ecological vulnerability to tipping points: A review of empirical approaches and their use for marine management. *Science of The Total Environment* **705**, 135838 (2020).

62. Elsawah, S. *et al.* Eight grand challenges in socio-environmental systems modeling. *SESMO* **2**, 16226 (2020).

63. Keys, P. W. *et al.* Anthropocene risk. *Nature Sustainability* **2**, 667–673 (2019).

64. Hill, R. *et al.* Working with Indigenous, local and scientific knowledge in assessments of nature and nature's linkages with people. *Current Opinion in Environmental Sustainability* **43**, 8–20 (2020).

65. Ogar, E., Pecl, G. & Mustonen, T. Science Must Embrace Traditional and Indigenous Knowledge to Solve Our Biodiversity Crisis. *One Earth* **3**, 162–165 (2020).

66. Tengo, M., Brondizio, E. S., Elmqvist, T., Malmer, P. & Spierenburg, M. Connecting Diverse Knowledge Systems for Enhanced Ecosystem Governance: The Multiple Evidence Base Approach. 13 (2014).

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

68. Gutzler, C. *et al.* Agricultural land use changes – a scenario-based sustainability impact assessment for Brandenburg, Germany. *Ecological Indicators* **48**, 505–517 (2015).

69. Kennedy, M. C., Ford, E. D., Singleton, P., Finney, M. & Agee, J. K. Informed multi-objective decision-making in environmental management using Pareto optimality: Multi-objective optimization. *Journal of Applied Ecology* **45**, 181–192 (2007).

70. Nagy, J. A., Benedek, J. & Ivan, K. Measuring Sustainable Development Goals at a Local Level: A Case of a Metropolitan Area in Romania. 15 (2018).

71. Miola, A. Measuring sustainable development goals performance_ How to monitor policy action in the 2030 Agenda implementation? *Ecological Economics* 10 (2019).

72. van Oudenhoven, A. P. E. *et al.* Key criteria for developing ecosystem service indicators to inform decision making. *Ecological Indicators* **95**, 417–426 (2018).

73. Dujardin, Y. & Chadès, I. Solving multi-objective optimization problems in conservation with the reference point method. *PLoS ONE* **13**, e0190748 (2018).

74. van Vuuren, D. P. *et al.* Pathways to achieve a set of ambitious global sustainability objectives by 2050: Explorations using the IMAGE integrated assessment model. *Technological Forecasting and Social Change* **98**, 303–323 (2015).

75. Chaplin-Kramer, R. *et al. Global critical natural assets*. http://biorxiv.org/lookup/doi/10.1101/2020.11.08.361014 (2020) doi:10.1101/2020.11.08.361014.

76. Strassburg, B. B. N. *et al.* Global priority areas for ecosystem restoration. *Nature* **586**, 724–729 (2020).

77. Baylis, K. *et al.* Mainstreaming Impact Evaluation in Nature Conservation: Mainstreaming impact evaluation. *CONSERVATION LETTERS* **9**, 58–64 (2016).

78. Sutherland, W. J. & Wordley, C. F. R. Evidence complacency hampers conservation. *Nat Ecol Evol* **1**, 1215–1216 (2017).

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

80. Leberger, R., Rosa, I. M. D., Guerra, C. A., Wolf, F. & Pereira, H. M. Global patterns of forest loss across IUCN categories of protected areas. *Biological Conservation* 108299 (2019) doi:10.1016/j.biocon.2019.108299.

81. Geldmann, J., Manica, A., Burgess, N. D., Coad, L. & Balmford, A. A global-level assessment of the effectiveness of protected areas at resisting anthropogenic pressures. *Proc Natl Acad Sci USA* **116**, 23209–23215 (2019).

82. Pullin, A. S. & Stewart, G. B. Guidelines for Systematic Review in Conservation and Environmental Management. *Conservation Biology* **20**, 1647–1656 (2006).

83. Sutherland, W. J., Pullin, A. S., Dolman, P. M. & Knight, T. M. The need for evidence-based conservation. *Trends in Ecology & Evolution* **19**, 305–308 (2004).

84. Bowler, D. E., Buyung-Ali, L. M., Knight, T. M. & Pullin, A. S. A systematic review of evidence for the added benefits to health of exposure to natural environments. *BMC Public Health* **10**, 456 (2010).

85. Konno, K. & Pullin, A. S. Assessing the risk of bias in choice of search sources for environmental meta-analyses. *Res Syn Meth* jrsm.1433 (2020) doi:10.1002/jrsm.1433.

86. Ribas, L. G. S., Pressey, R. L. & Bini, L. M. Estimating counterfactuals for evaluation of ecological and conservation impact: an introduction to matching methods. *Biol Rev* brv.12697 (2021) doi:10.1111/brv.12697.

87. Jellesmark, S. *et al.* A counterfactual approach to measure the impact of wet grassland conservation on UK breeding bird populations. *Conservation Biology* cobi.13692 (2021) doi:10.1111/cobi.13692.

88. Joppa, L. N. & Pfaff, A. Global protected area impacts. *Proceedings of the Royal Society of London B: Biological Sciences* rspb20101713 (2010) doi:10.1098/rspb.2010.1713.

89. Ferraro, P. J., Sanchirico, J. N. & Smith, M. D. Causal inference in coupled human and natural systems. *Proc Natl Acad Sci USA* **116**, 5311–5318 (2019).

90. Smokorowski, K. E. & Randall, R. G. Cautions on using the Before-After-Control-Impact design in environmental effects monitoring programs. *FACETS* **2**, 212–232 (2017).

91. *Remote Sensing of Plant Biodiversity*. (Springer International Publishing, 2020). doi:10.1007/978-3-030-33157-3.

92. Brown, C., Seo, B. & Rounsevell, M. Societal breakdown as an emergent property of large-scale behavioural models of land use change. *Earth Syst. Dynam.* **10**, 809–845 (2019).

93. Kim, H. *et al.* A protocol for an intercomparison of biodiversity and ecosystem services models using harmonized land-use and climate scenarios. *Geosci. Model Dev.* **11**, 4537–4562 (2018).

94. Willcock, S. *et al.* Ensembles of ecosystem service models can improve accuracy and indicate uncertainty. *Science of The Total Environment* **747**, 141006 (2020).

95. Pereira, H. M. *et al.* Scenarios for Global Biodiversity in the 21st Century. *Science* **330**, 1496–1501 (2010).

96. PBL Netherlands Environmental Assessment Agency. *Global modelling of biodiversity and ecosystem services*. (2019).

97. Banerjee, O. *et al.* Global socio-economic impacts of changes in natural capital and ecosystem services: State of play and new modeling approaches. *Ecosystem Services* **46**, 101202 (2020).

98. Johnson, J. A. *et al. The Economic Case for Nature: A global Earth-economy model to assess development policy pathways*. https://openknowledge.worldbank.org/handle/10986/35882 (2021).

99. PBL Netherlands Environmental Assessment Agency. *From visions to scenarios for nature and nature's contributions to people for the 21st century*. (2019).

100. Acosta, L. A. *et al.* Chapter 2 Using scenarios and models to inform decision making in policy design and implementation. in *The methodological assessment report on scenarios and models of biodiversity and ecosystem services* (IPBES, 2016).

101. Brotons, L. *et al.* Chapter 4 Modelling impacts of drivers on biodiversity and ecosystems. in *The methodological assessment report on scenarios and models of biodiversity and ecosystem services* (IPBES, 2016).

102. Cheung, W. W. L. *et al.* 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* (IPBES, 2016).

103. Regan, H. M., Colyvan, M. & Burgman, M. A. A taxonomy and treatment of uncertainty for ecology and conservation biology. *Ecological Applications* **12**, 618–628 (2002).

104. Dunford, R., Harrison, P. A. & Rounsevell, M. D. A. Exploring scenario and model uncertainty in cross-sectoral integrated assessment approaches to climate change impacts. *Climatic Change* **132**, 417–432 (2015).

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

106. Ceaușu, S. *et al.* Ecosystem service mapping needs to capture more effectively the biodiversity important for service supply. *Ecosystem Services* **48**, 101259 (2021).

107. Harrison, P. A. *et al.* Linkages between biodiversity attributes and ecosystem services: A systematic review. *Ecosystem Services* **9**, 191–203 (2014).

108. O'Neill, B. C. *et al.* Achievements and needs for the climate change scenario framework. *Nat. Clim. Chang.* **10**, 1074–1084 (2020).

109. Mouquet, N. *et al.* REVIEW: Predictive ecology in a changing world. *J Appl Ecol* **52**, 1293–1310 (2015).

110. Urban, M. C. *et al.* Improving the forecast for biodiversity under climate change. *Science* **353**, aad8466–aad8466 (2016).

111. Callaghan, C. T., Nakagawa, S. & Cornwell, W. K. Global abundance estimates for 9,700 bird species. *Proc Natl Acad Sci USA* **118**, e2023170118 (2021).

112. Petchey, O. L. *et al.* The ecological forecast horizon, and examples of its uses and determinants. *Ecol Lett* **18**, 597–611 (2015).

113. Willcock, S. *et al.* Machine learning for ecosystem services. *Ecosystem Services* **33**, 165–174 (2018).

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

115. Liu, J. *et al.* Nexus approaches to global sustainable development. *Nat Sustain* **1**, 466–476 (2018).

116. Singh, G. G. *et al.* A rapid assessment of co-benefits and trade-offs among Sustainable Development Goals. *Marine Policy* **93**, 223–231 (2018).

117. Mayrhofer, J. P. & Gupta, J. The science and politics of co-benefits in climate policy. *Environmental Science & Policy* **57**, 22–30 (2016).

118. Polasky, S. *et al.* Where to put things? Spatial land management to sustain biodiversity and economic returns. *Biological Conservation* **141**, 1505–1524 (2008).

119. Ferguson, S. M., Phillips, P. E. M., Roth, B. L., Wess, J. & Neumaier, J. F. Direct-Pathway Striatal Neurons Regulate the Retention of Decision-Making Strategies. *Journal of Neuroscience* **33**, 11668–11676 (2013).

120. Wise, R. M. *et al.* Reconceptualising adaptation to climate change as part of pathways of change and response. *Global Environmental Change* **28**, 325–336 (2014).

121. Sharpe, B., Hodgson, A., Leicester, G., Lyon, A. & Fazey, I. Three horizons: a pathways practice for transformation. *E&S* **21**, art47 (2016).

122. Haug, C. *et al.* Navigating the dilemmas of climate policy in Europe: evidence from policy evaluation studies. *Climatic Change* **101**, 427–445 (2010).

123. Andam, K. S., Ferraro, P. J., Pfaff, A., Sanchez-Azofeifa, G. A. & Robalino, J. A. Measuring the effectiveness of protected area networks in reducing deforestation. *Proceedings of the National Academy of Sciences* **105**, 16089–16094 (2008).

124. Smismans, S. Policy Evaluation in the EU: The Challenges of Linking *Ex Ante* and *Ex Post* Appraisal. *Eur. j. risk regul.* **6**, 6–26 (2015).

125. Wiek, A. & Iwaniec, D. Quality criteria for visions and visioning in sustainability science. *Sustain Sci* **9**, 497–512 (2014).

126. Preiser, R., Pereira, L. M. & Biggs, R. (Oonise). Navigating alternative framings of human-environment interactions: Variations on the theme of 'Finding Nemo'. *Anthropocene* **20**, 83–87 (2017).

Acknowledgement

We offer our tribute to the life of Prof. Bob Scholes whose life and leadership dedicated to advancing conservation science and improving quality of life for all living beings on Earth inspired us immensely in this manuscript. This manuscript resulted from synthesis of two IPBES workshops, two external workshops and additional rounds of expert consultations with the IPBES expert group on scenarios and models. We thank the participants of IPBES workshops for conceiving the ideas on applying the Nature Futures Framework in developing scenarios (Vancouver, March 2019) and in modelling (The Hague, June 2019). We appreciate sDiv sUrBio2050 (Leipzig, September 2019) and GEO BON EBV2020 (D.C., October 2019) workshops for testing the feasibility of the proposed concepts and approaches in this manuscript with modellers on biodiversity and ecosystem functions and services in urban systems and in terrestrial, marine and freshwater systems respectively. We also thank the IPBES editorial committee for their review and constructive comments to the manuscript.

The authors acknowledge the Peter Wall Institute for Advanced Studies and its funding support to the Wall Scholars program in hosting the 2019 Vancouver Workshop in Canada. The authors also acknowledge the PBL Netherlands Environmental Agency and support of the government of the Netherlands for the hosting of the 2019 The Hague Workshop and for the provision of technical and graphical support. HJK and HMP gratefully acknowledge support of iDiv funded by the German Research Foundation (DFG– FZT 118, 202548816). WLC acknowledges funding support from NSERC Canada Discovery Grant. AA acknowledges support from the Helmholtz Association. JJK acknowledges support from The Swedish Research Council for Sustainable Development FORMAS Grant nr. 2019-01648. LP was supported in part by the National Research Foundation of South Africa (Grant Number 115300), the Swedish Research Council FORMAS (Project No. 2020-00670) and the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). TDE and CCCW acknowledge support from the Nippon Foundation Nereus Program. CJL acknowledges support from NIWA Coasts and Oceans Programme (Project No. COME1903) and the New Zealand Sustainable Seas National Science Challenge (MBIE Contract No. CO1X1515). YJS acknowledges support by the Biodiversa and Belmont Forum project SOMBEE (BiodivScen ERA-Net COFUND programme, ANR contract n°ANR-18-EBI4-0003-01), the European Union's Horizon 2020 research and innovation programme under grant agreement No 869300 (FutureMARES), and the Pew marine fellows programme. FS was funded by the New Zealand Sustainable Seas National Science Challenge Phase I (Project: SUSS16203). JJA acknowledges support by the Nippon Foundation-Ocean Litter Project. ICC received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement: 766417. SH acknowledges support by the Asian Pacific Network for Global Change Research (CRRP2018-03MY-Hashimoto). TH acknowledges support by the German Federal Ministry of Education and Research (BMBF) and the European Research Area for Climate Services ERA4CS (project funding reference 518, grant number 01LS1711D, ISIpedia project). HO acknowledges support from the Environment Research and Technology Development Fund (JPMEERF20202002) of the Environmental Restoration and Conservation Agency of Japan. BWM acknowledges support by the U.S. Geological Survey, North Central Climate Adaptation Science Center. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government. OS acknowledges the support by Environment Research and Technology Development Fund (S-15, JPMEERF16S11500), Japan Ministry of the Environment. URS acknowledges the support by the Ocean Canada Partnership supported by the Social Sciences and Humanities Research Council of Canada.

Contributions

HMP coordinated this work as co-chair of the IPBES Expert Group. HJK, HMP, WWLC, SF and GP developed the idea for the manuscript and led the discussions and post-workshop synthesis. All authors participated in workshops and contributed substantially in co-developing concepts and approaches presented in the manuscript. HJK led the writing and revision process with guidance of HMP. All authors improved the structure and contents with comments and revisions. HJK developed the figures based on input from all authors and graphical support from Sandy van Tol at PBL. All authors gave final approval for publication.

SUPPLEMENTARY INFORMATION

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

HyeJin Kim, Garry Peterson, William W. L. Cheung, Simon Ferrier, Rob Alkemade, Almut Arneth, Jan J. Kuiper, Sana Okayasu, Laura Pereira, Lilibeth A. Acosta, Rebecca Chaplin-Kramer, Eefje den Belder, Tyler D. Eddy, Justin A Johnson, Sylvia Karlsson-Vinkhuyzen, Marcel T.J. Kok, Paul Leadley, David Leclère, Carolyn J. Lundquist, Carlo Rondinini, Robert J. Scholes, Machteld Schoolenberg, Yunne-Jai Shin, Elke Stehfest, Fabrice Stephenson, Piero Visconti, Detlef van Vuuren, Colette C.C. Wabnitz, Juan José Alava, Ivon Cuadros-Casanova, Maria A. Gasalla, Ghassen Halouani, Mike Harfoot, Shizuka Hashimoto, Thomas Hickler, Tim Hirsch, Grigory Kolomytsev, Brian W. Miller, Haruka Ohashi, Maria Gabriela Palomo, Alexander Popp, Roy Paco Remme, Osamu Saito, U. Rashid Sumalia, Simon Willcock, Henrique M. Pereira

I. Participants' perspectives on the application of Nature Futures Framework in scenarios and models (Source: 2019 Vancouver Stakeholder Workshop[1])

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).
- 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, financers, 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

II. Indicators discussed on the Nature Futures Framework

Source: 2019 Vancouver Stakeholder Workshop[1]

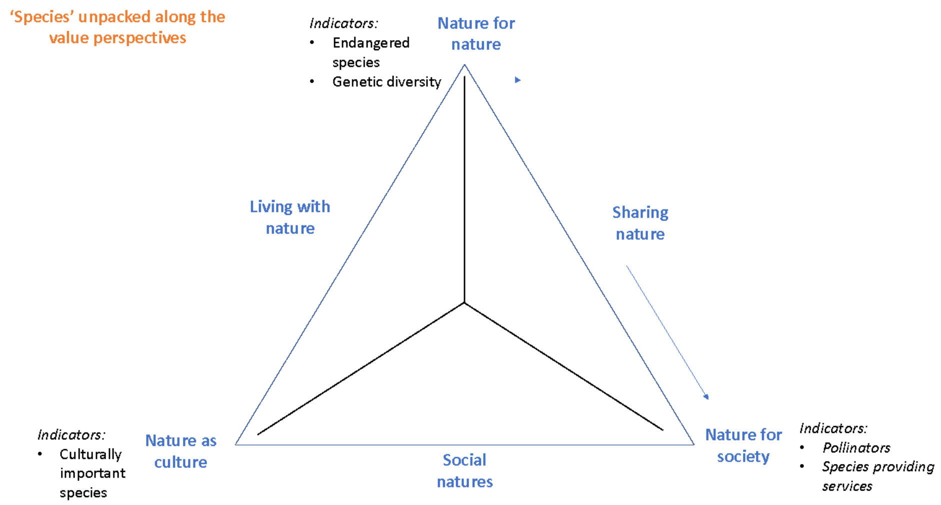
		Nature for Nature	Nature for Society	Nature as Culture
OCEAN				
Management	Total sustainable catch		↗ (1)	
	% fish from aquaculture			
	Level of management decision	Global		Local
	Area with no-take marine protected area	↗ (2) 30%		
	Area under community-based management			↗ (3)
State	% fish stocks depleted	↘(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)	
	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	↗ ↗ ↗		

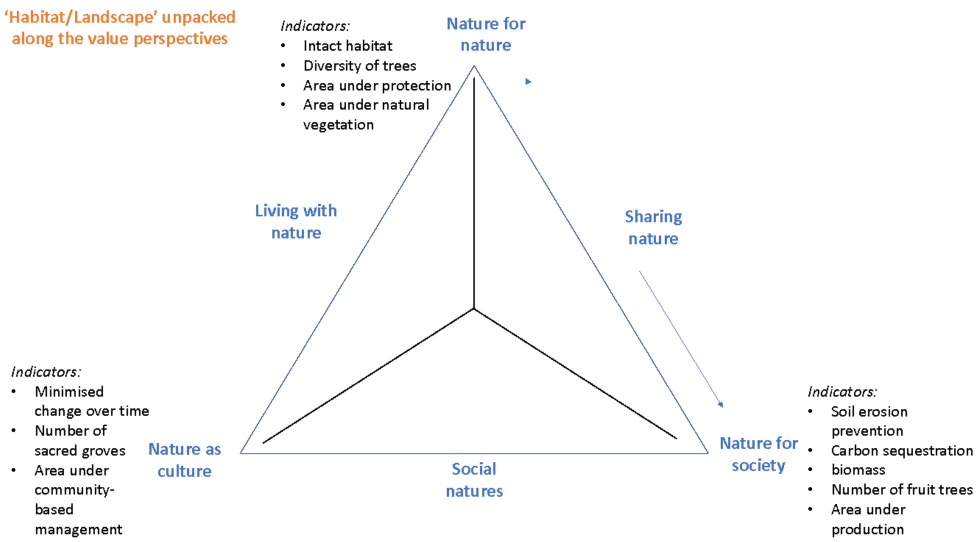
	Green spaces that are self-sustained	↗		
Pressure	Air quality regulation	↗	↗ (1)	
	Water quality regulation (waste water management)	↗	↗ (2)	
	Community gardening			↗ (2)
	Urban gardening		↗	
	Green roofs / nature-based solution		↗	
	Level of management decision	Global		Local
State	Species richness (no-take 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

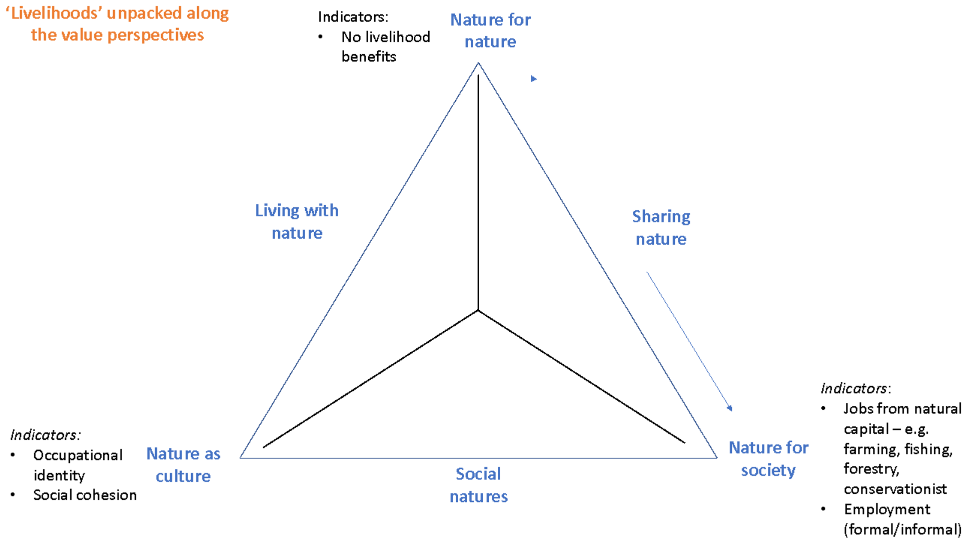
Source: 2019 The Hague Modellers Workshop[2]

	Management	**State**	**Benefit**
Nature for Nature	*Indicator: Protected areas* Marine: WDPA - No take Terrestrial: WDPA 1-3	*Endangered sp. and habitat* M: Endangered species, Coral reef cover T: endangered sp., pristine forest, wetland extent apex predators; megaherbivores; "trophic rewilding"	M: diving sites T: wildlife watching
Nature for Society	*Sustainable use areas* M: Mgmt effectiveness (country level) T: WDPA 4-6	M: % depleted stocks T: CO_2 sequestration, water purification, soil retention nature-based solution	M: Sustainable fish catch T: Ag production w/o erosion or water pollution, storm protection
Nature as Culture	*Comm-based mgmt* 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 location? sacred forests? indigenous land	*Cultural keystones* 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 UNESCO world heritage sites*, maybe MABs and indigenous reserves, certain certifications*	*# Jobs (livelihoods?)* M: number of jobs T: local livelihoods books; cultural roles; shaman; cultural activities co-management; local control over nature; social-ecological feedbacks

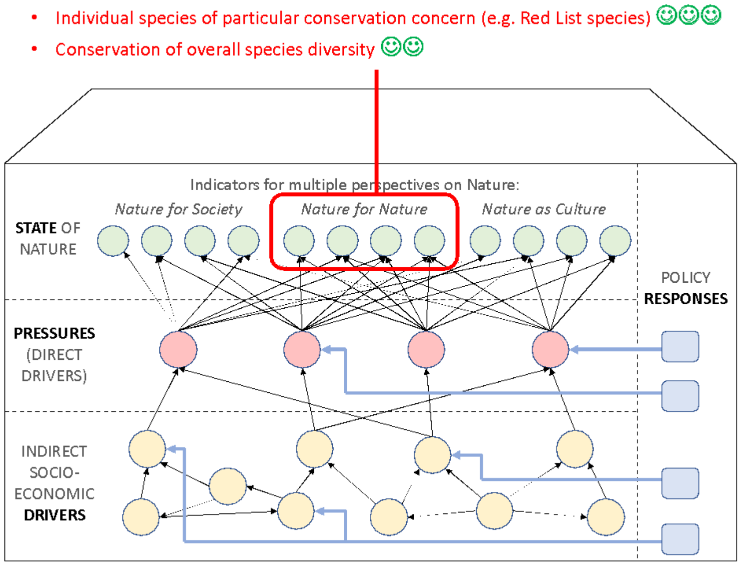
III. Assessing single policy using the Nature Futures Framework with indicators that measure three value perspectives (Source: 2019 Vancouver Stakeholder Workshop[1])

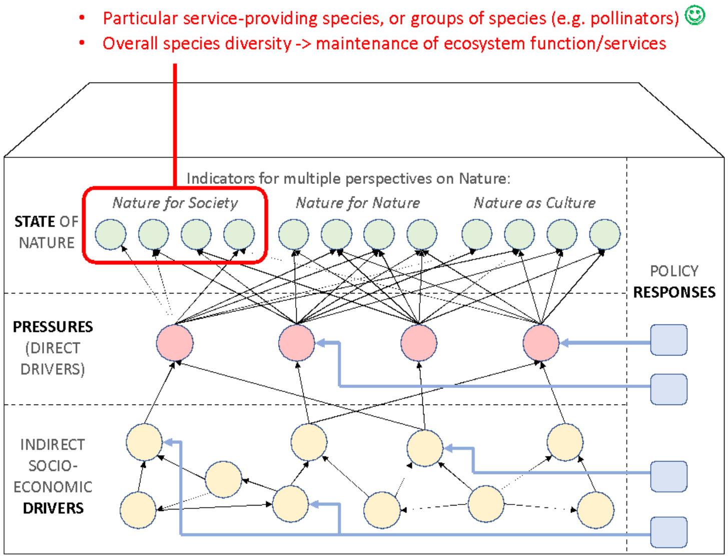


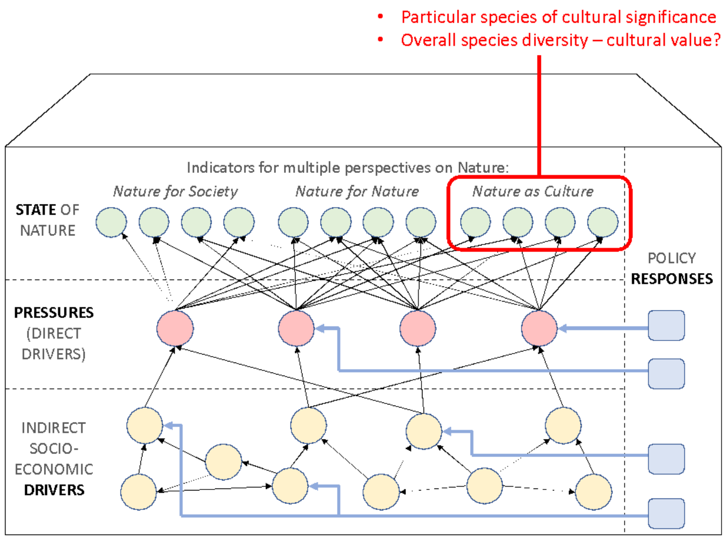




IV. Assessing systems dynamics using the Nature Futures Framework and Driver-Pressure-State-Impact-Response (Source: 2019 Vancouver Stakeholder Workshop[1])







V. Nature Futures modellable questions assessed on novelty, feasibility, scale, policy impact

(Source: 2019 The Hague Modellers Workshop[2])

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: ● 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: ● Cultural identity maintained (species still exist) ● Influence of change/drivers	Identity: 10 Drivers: 10	5	8
Cultural landscapes and biodiversity ● Provision of BES	Local/regional: 10 (has been done) Global: 2 (how to scale up)	Local/regional : 5 Global: 10	10

● Resilience to drivers/climate change			
Management intensity ● 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 ● 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 ● 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 ● 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?

References

1. PBL Netherlands Environmental Assessment Agency. *From visions to scenarios for nature and nature's contributions to people for the 21st century*. (2019).
2. PBL Netherlands Environmental Assessment Agency. *Global modelling of biodiversity and ecosystem services*. (2019).