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

HyeJin Kim*[1,2], Garry D. 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[22,23], Robert J. Scholes[9], Machteld Schoolenberg[6], Yunne-Jai Shin[24], Elke Stehfest[6], Fabrice Stephenson[20], Piero Visconti[19], Detlef van Vuuren[6,10], Colette C.C. Wabnitz[4,25], Juan José Alava[4], Ivon Cuadros-Casanova[22], Kathryn K. Davies[20,26], Maria A. Gasalla[27], Ghassen Halouani[28], Mike Harfoot[29], Shizuka Hashimoto[30], Thomas Hickler[31,32], Tim Hirsch[33], Grigory Kolomytsev[34], Brian W. Miller[35], Haruka Ohashi[36], Maria Gabriela Palomo[37], Alexander Popp[38], Roy Paco Remme[12,39], Osamu Saito[40], U. Rashid Sumalia[4,41], Simon Willcock[42,43], Henrique M. Pereira*[1,2,44]

## Abstract

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

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

*Corresponding authors: HyeJin Kim, Henrique Pereira
German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig
Puschstrasse 4, 04103 Leipzig, Germany
hyejin.kim@idiv.de, henrique.pereira@idiv.de

[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] Center for Global Wildlife Conservation, State University of New York College of Environmental Science and Forestry, USA
[24] Univ Montpellier, IRD, IFREMER, CNRS, MARBEC, Montpellier, France
[25] Stanford Center for Ocean Solutions, Stanford University, Stanford, CA, USA
[26] Tufts University, Medford, MA 02155, USA
[27] University of Sao Paulo, Oceanographic Institute, Fisheries Ecosystems Laboratory (LabPesq), Brazil
[28] IFREMER, Unité halieutique Manche Mer du Nord Ifremer, Boulogne-sur-mer, France
[29] UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), Cambridge, UK
[30] Department of Ecosystem Studies, University of Tokyo, Japan
[31] Senckenberg Biodiversity and Climate Research Centre (BiK-F), Frankfurt, Germany
[32] Department of Physical Geography, Goethe-University, Frankfurt, Germany
[33] Global Biodiversity Information Facility Secretariat, Copenhagen Ø, Denmark
[34] I.I. Schmalhausen Institute of Zoology of National Academy of Sciences of Ukraine, Kyiv, Ukraine
[35] U.S. Geological Survey, North Central Climate Adaptation Science Center, Fort Collins, CO, USA
[36] Department of Wildlife Biology, Forestry and Forest Products Research Institute (FFPRI), Forest Research and Management Organization, Japan
[37] Natural History Museum of Argentina, Parque Centenario, Argentina
[38] Potsdam Institute for Climate Impact Research (PIK), Member of the Leibniz Association, Potsdam, Germany
[39] Institute of Environmental Sciences, Leiden University, Leiden, The Netherlands
[40] Institute for Global Environmental Strategies (IGES), Kanagawa, Japan
[41] School of Public Policy and Global Affairs, University of British Columbia, Vancouver, Canada
[42] Rothamsted Research, Harpenden, UK
[43] School of Natural Sciences, Bangor University, Bangor, UK
[44] CIBIO (Research Centre in Biodiversity and Genetic Resources)–InBIO (Research Network in Biodiversity and Evolutionary Biology), Universidade do Porto, Vairão, Portugal

## 1. The need for positive scenarios in transformative change

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

The drivers of biodiversity loss and other environmental degradation are rooted in population growth and inequality (Hamann et al., 2018), unsustainable production and consumption patterns (Hoekstra and Wiedmann, 2014), provision of environmentally harmful subsidies (Dempsey et al., 2020), poor governance regimes and limited recognition of the importance of biodiversity conservation (Smith et al., 2003), and the firm reliance on fossil fuels (IPCC, 2015) among others. To effectively address these and to increase the willingness to enhance biodiversity conservation policies, we need societal transformations across sectors at all levels concurrently and synergistically (Chan et al., 2020). Furthermore, revitalizing the relationship between people and nature is fundamental in increasing priority for sustainability issues, in particular, but not exclusively, in developed countries (Amel et al., 2017), with a growing share of responsibility on remote biodiversity and habitat loss from natural resource exploitation (Swartz et al., 2010), international trade (Chaudhary and Kastner, 2016) or degraded ecosystem capacity (Marques et al., 2019). We need changes in norms and beliefs that result in behavioural change (Kinzig et al., 2013), aided by effective governance (Amano et al., 2018), financial instruments (Waldron et al., 2017), as well as individual champions who inspire collective action (Amel et al., 2017). Most importantly, optimism and empathy can contribute to responsible actions if actors see that they can make a difference (Blythe et al., 2021; Knowlton, 2019) and when the process engages the imagination of transformative futures (Pereira et al., 2019).

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

This paper reflects on how the NFF can be applied in modelling Nature Futures scenarios to inform policy. First, we present three key building blocks of the NFF for developing qualitative and quantitative scenarios and models. We then describe three types of applications for integrating Nature Futures scenarios in policy processes. This paper aims to help enhance the utility of scenarios and modelling in the implementation of multiscale policy frameworks such as the Post-2020 Global Biodiversity Framework (GBF) of the Convention on Biological Diversity (CBD) and the United Nations Sustainable Development Goals (SDG) agenda with critical challenges to be overcome.

## 2. Key building blocks for Nature Futures scenarios

This section presents three key building blocks that are important to incorporate in qualitative and quantitative scenarios of Nature Futures. The order of building blocks 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. The NFF attempts to capture these in three main perspectives. The Nature for Nature (NN) perspective appreciates and preserves nature for what it is and does and maps to intrinsic and existence values of biodiversity (e.g., maintaining natural processes and structures such as evolution and migration) (Chan et al., 2016). The Nature for Society (NS) perspective focuses on instrumental values as in benefits nature provides to people (e.g. supporting crop production and climate regulation) (Pascual et al., 2017). Finally, the Nature as Culture (NC) perspective values the relationships that nature and people co-create, not as separate entities but as an indivisible whole (e.g., preserving emblematic species, sacred landscapes, and traditional knowledge) (Himes, 2018). These value perspectives of the Nature Futures Framework are envisaged to broaden and diversify stakeholders' visions for nature and people through exploring, mapping and combing different futures on the gradients such as management intensity, instrumental values and cultural importance of nature (Figure 1).

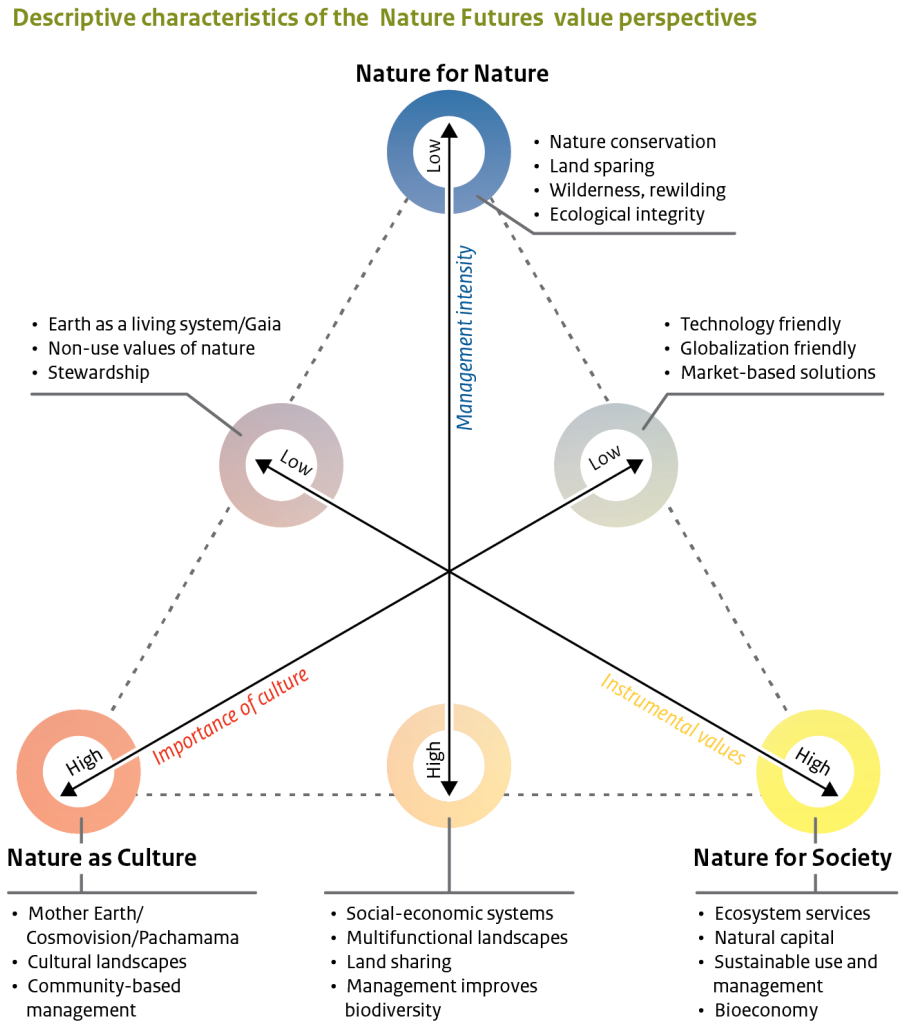


**Figure 1.** Descriptive characteristics of the Nature Future value perspectives and the space between these perspectives. Most systems and places in the world would have a mix of these values and map somewhere inside the triangle of the Nature Futures Framework.

However, the three value perspectives on nature are not mutually exclusive of each other – in fact, they are intricately connected and can reinforce each other (Martín-López, 2021). Keystone species are such an example with their functional role benefiting both nature and people (e.g., top predators control herbivore populations and reduce damage to crops, animal movements mediate carbon exchange between ecosystems and the atmosphere) (Martin et al., 2020; Schmitz et al., 2018). Thus, although we represent the Nature Futures state space of social-ecological systems with three axes as orthogonal for simplicity (Figure 2a), a more precise representation would have these axes as partially overlapping, as some of the values overlap across the three perspectives (Figure 2b). This means an increase of the values along one axis can per se correspond to an increase along another axis. 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.

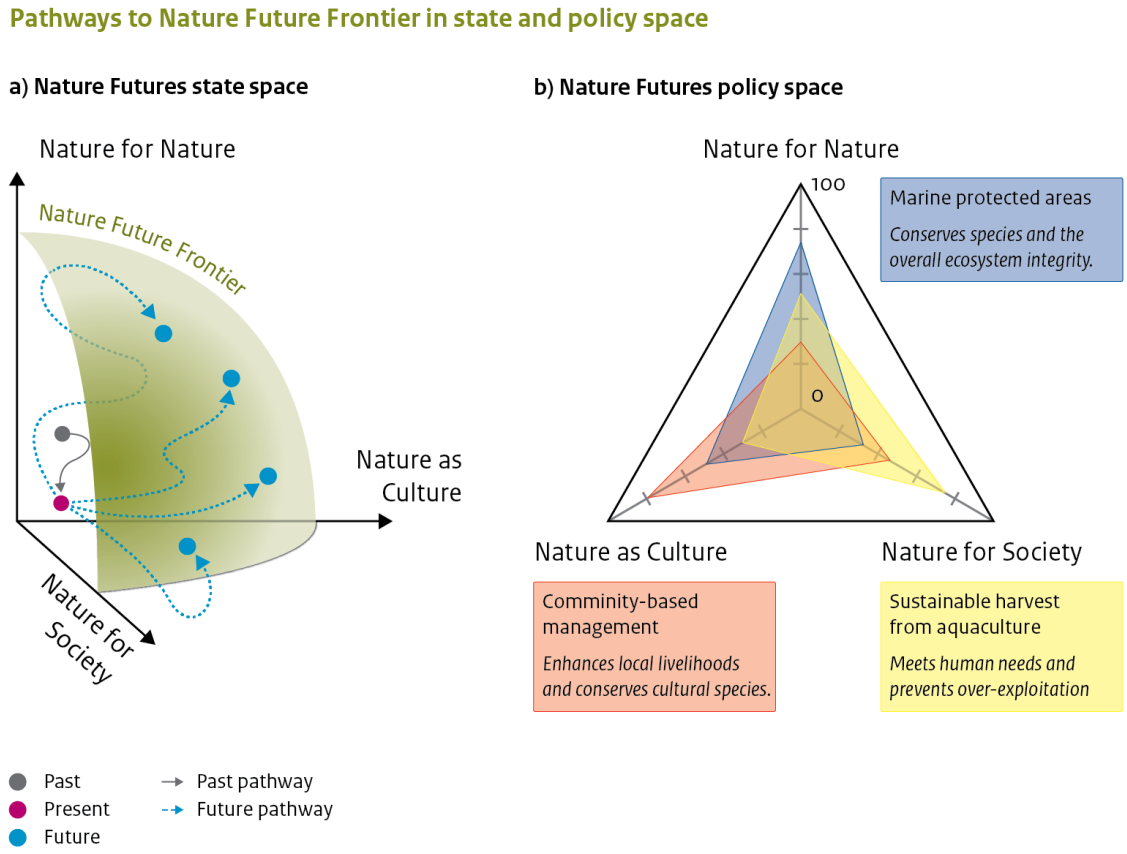


**Figure 2**. (a) Nature Futures state space and frontier (green concave with blue dots) with multiple pathways to desirable futures where all three value perspectives improve relatively to present. (b) Nature Futures policy space with interventions and indicators scored and mapped across value perspectives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

The state of a social-ecological system can be plotted into a multidimensional state space by evaluating the system on each dimension of the value perspectives (Figure 2a). Conceptually speaking, these perspectives can then be seen as projections representing both the historical pathway of a system from the past to the present and future pathways towards desirable endpoints (so-called 'Nature Futures

Frontier') in this state space (Figure 2a). Typically, desirable Nature Futures correspond to points in the state space where there is an improvement in all three value perspectives into the future relative to the present. We can assess particular actions or policies to see how the system moves towards different points of the state space. To do this, we can score the relative contribution of a given action or policy on the axes representing different value perspectives and map them in a policy space of Nature Futures (Figure 2b). Important to point out that many interventions can be appropriate and are necessary under more than one perspective. In this sense, many systems and future scenarios of Nature Futures would map somewhere inside the NFF triangle with a mixture of interventions with different degrees. As an illustrative example, there are different categories of protection in protected areas – they can strictly limit human access, allow access for active management and recreational use, or be placed in indigenous peoples' land – all with the mixed representation of value perspectives and different short to long term co-benefits and trade-offs.

Furthermore, one can envision a world where different locations are managed exclusively for one of the value perspectives at the more local scale, but at the regional and certainly, at the global scale, all three value perspectives must co-exist given diversity in the scale of geographic coverage. 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, clustering a cloud of points towards the centre or dispersing them across all corners of the frontier.

### *2.2 Social-ecological systems with feedbacks*

Feedbacks between people and nature are central to the IPBES conceptual framework (Díaz, 2015). Understanding these feedbacks is key to understanding what can move the world towards or away from nature and people positive futures. However, only limited social-ecological feedbacks are captured in the existing environmental models (Pereira et al., 2021).

In Nature Futures scenarios, we want to find interventions that lead to improvements in more than one value perspective or even trigger synergies in interventions across the perspectives in social-ecological systems. For instance, securing land ownership and management by indigenous and local communities (predominantly representing NC) can maintain intact habitats to conserve biodiversity (NN), preserving long-standing traditional knowledge and cultural heritage, thereby ensuring societal benefits from sustainable livelihoods (NS) (Dinerstein et al., 2020). Thus, identifying interventions for a specific or combination of nature value perspectives are particularly important for understanding where multiple values are present and can reinforce each other.

Different feedback dynamics are more dominant in each value perspectives of the NFF, 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 (Robinson et al., 2018), but only partially (e.g., the role of pollination in food provision but not the soil). Furthermore, many models represent agricultural land conversion in which crop production interacts with demand for it to drive land-use change (Lambin and Meyfroidt, 2011) and, in some cases, changes in production feedback to impact human wellbeing (Chaplin-Kramer et al., 2019). But we lack models representing how some interventions such as land-use change 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 (McLauchlan et al., 2020), but for instance, the role of keystone species, such as beavers creating wetlands and landscape heterogeneity by felling trees and blocking water flows, is still missing in estimating their eventual contributions to human wellbeing (Willby et al., 2018) (Figure 3).

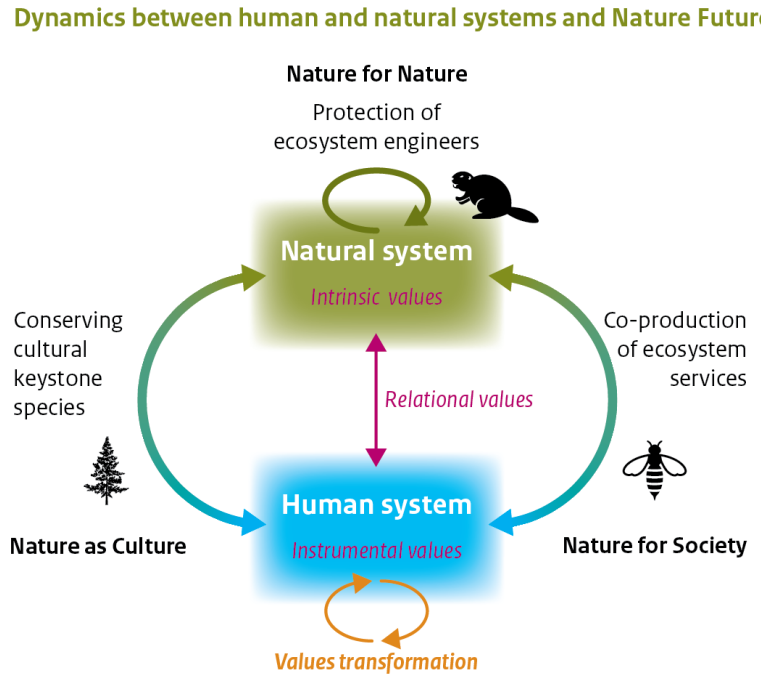


**Figure 3.** A simple diagram with feedback loops represents the dynamics between human and natural systems within and between the systems that reflect Nature Futures value perspectives.

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

### *2.3 Indicators of knowledge and data as multiple evidence bases*

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

Using 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 potential impacts on goals set on nature, nature's contributions to people and quality of life. As illustrated in Table 3 and Figure 4, interventions and goals can be cross-cutting, for example, supporting community learning facilities that enhance public awareness on conservation and sustainability issues and preventing species extinction and ecosystems degradation for intergenerational equity – or they can have a "home" in one of the value

perspectives, as also demonstrated in the policy space of Figure 2b. For life satisfaction as a goal on quality of life, NN can be measured by the enjoyment of experiencing nature and knowing other species are protected, NS from using quality goods from nature and knowing that they are equitably shared or NC from preserving nature-based cultural heritage and thereby maintaining social cohesion (Table 1).

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

**Table 1.** Illustrative features of the Nature Future scenarios 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**<br>- Institutions and governance | Promoting national and international systems and cooperation on biodiversity issues<br>*(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<br>*(e.g., LIT. number of countries/municipalities that have assigned rights to nature in their constitutions)* | Developing environmentally friendly infrastructure for human settlement<br>*(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<br>*(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<br>*(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<br>*(e.g., % agro-environmental measures allocated to fertile lands and their productivity level)* | Implementing agro-environmental measures targeting maximum co-production of ecosystem services<br>*(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<br>*(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<br>(*e.g., number of public events on conservation and sustainability topics)* | Creating protection, management and education facilities for wildlife watching<br>*(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<br>*(e.g., amount of investment of private firms deploying nature-based solutions)* | Establishing community associations for supporting local production and consumption and fair trade<br>*(e.g., INI D2. Trends in consumption of diverse locally-produced food)* |
| **Interventions on direct drivers**<br>- Anthropogenic and natural | Designating different types of protected areas<br>*(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<br>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 | Community based management (CBM) of natural resources, e.g. other effective area-based conservation measures (OECMs) where wild crop relatives grow |

| Framework components | Cross-cutting | Nature for Nature | Nature for Society | Nature as Culture |
|---|---|---|---|---|
| | | *(e.g., % of total land being rewilded, reforested and restored)* | *(e.g., % contribution of NBS to climate change mitigation by type)* | *(e.g., % of total land with wild crop relatives by management type)* |
| **Goals on nature**<br>- Biodiversity and ecosystems | Preventing species from extinction<br>*(e.g., CBD AT12 Species Protection Index, number of species prevented from extinction)* | Protecting species important for biodiversity, ecological processes and ecosystem functions<br>(*e.g., protection status of species important for ecosystems)* | Protecting species and ecosystems important for material and regulating services<br>(*e.g., protection status of species important for providing ecosystem services)* | Protecting species and landscape important for local communities and cultural heritage<br>*(e.g., protection status of species important for cultural reasons)* |
| **Goals on nature's contributions to people**<br>- Ecosystem services | Preventing degradation of ecosystem functions and services<br>*(e.g. trends in natural ecosystem extent, water regulation)*<br>Equitable sharing of benefits from nature<br>*(e.g., distribution, stocks and flows of ecosystem services by type across regions)* | Advancing remote and longer term benefits from conserving nature<br>*(e.g., % change in carbon capture and sequestration from nature by type – forest, oceans, etc.)* | Provision of immediate material and regulating services from nature<br>*(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<br>(*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)<br>*(e.g., SDG 2.5.2 % of undernourished people*<br>*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<br>*(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<br>*(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<br>*(e.g., INI L1. Possibility to perform traditional occupations (such as pastoralism, hunting/gathering, shifting cultivation, fishing) without restriction as a proxy)* |

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

*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.

## 3. Modelling Nature Futures scenarios to inform policy

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

**Table 2.** Modelling application of Nature Futures scenarios in 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, particularly, direct drivers (e.g., location and types of protected areas)? | What societal transformations need to occur to achieve long-term visions for people and nature? How do changes in nature's contributions to people affect societal decisions (e.g., how do benefits of protected areas 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** (examples) | Emphasizes past observations. Counterfactuals can be examined with techniques such as statistical matching or before-after control impact | Models of impacts of direct drivers on biodiversity and ecosystem services models | Integrated assessment models at large scales, dynamic social-ecological models at smaller scales |
| **Key modelling challenges** | Integrating time series monitoring in biodiversity and ecosystem services, impact models of diverse drivers | Connecting biodiversity, ecosystem services and quality of life, incorporating a broader set of drivers in impact models | Long term social-ecological feedbacks at large scales, and incorporation of tipping points/regime shift |

### *3.1 Objectives and methods for modelling application*

The Nature Futures Framework can be used in exploring a much broader array of interventions, compared to previous environmental scenarios, integrating diverse values, roles and benefits of nature. Thus, it can help identify the interventions and monitor the goals set in policy frameworks at local, national and global scale (e.g., CBD National Biodiversity Strategy and Action Plans, CBD National Reports, CBD Post-2020 Global Biodiversity Framework). The NFF can be applied retrospectively to evaluate the performance of implemented 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) (Table 2).

For policy review, evidence synthesis can use methods such as systematic review (Bowler et al., 2010) and meta-analyses (Konno and Pullin, 2020) or impact assessment employing econometric and statistical techniques such as matching (Schleicher et al., 2020) and before-after control impact (Ferraro et al., 2019). Counterfactual analysis of direct drivers on biodiversity and nature's contributions to people can inform where and how biodiversity has been changing due to implemented policies (e.g. protected areas with different priorities on nature, people and culture) compared to those areas where

such measures did not take place (Sze et al., 2021). Furthermore, impact models of direct drivers on biodiversity can fill spatial and temporal gaps in historical data that are then key to assess impacts on the ecosystem services (Fernández et al., 2020).

For policy screening, models can predict the consequences for different policy interventions, particularly direct drivers (e.g., location and types of protected areas), reflecting different nature value perspectives on biodiversity, ecosystem services, and quality of life (O'Connor et al., 2021). For these relatively short-term analyses (e.g., one decade), modelling a broader range of direct drivers are more important than incorporating full dynamics of indirect drivers, which may not be necessary or feasible.

For policy design and agenda-setting, a broader set of social-ecological feedbacks should be modelled to identify societal transformation pathways to different Nature Future scenarios in achieving long-term visions, ensuring that the impact of interventions on nature on people inform the future decisions (e.g., how benefits of protected areas inform societal changes). Here, both the modelling of interventions on indirect drivers and the key feedbacks in social-ecological systems are essential in developing robust scenarios (Figure 4).

### *3.2 Scenario analysis in state space and policy space*

For scenarios analyses to support policy using the NFF, a single policy can be scored and mapped in the Nature Futures policy space to assess how the system is likely to evolve along with the three perspectives (Figure 2b). Although most policies will impact the system across the three value perspectives, some policies may particularly favour one perspective over the others. When it is done well in discussion with stakeholders, assigning interventions to different nature value perspectives allows us to evaluate the consequences of different preferences and priorities inherent in decision options.

Furthermore, a combination of policies can be tested through a modelling framework and analyze how the key levers can improve the system along the three axes in the state space and eventually towards the Nature Futures Frontier (Figure 2a). For example, marine protected areas (predominantly representing NN), community-based management (NC) and sustainable harvest from aquaculture (NS) can be assessed individually in the policy space (Figure 2b) or together in an integrated way in the state space (Figure 2a). Furthermore, multiple variables and indicators can be selected to generate Nature Futures scenarios in state space as an output of models (as illustrated in Table 1). A modelling framework can be developed (as shown in Figure 4) to assess the system's state. This means, to represent the evolution of the system quantitatively in a three-dimensional state space, some projections of indicators with a single score per axis are needed into the three Nature Futures axes. For instance, the overall score along the Nature for Nature axis can be calculated by deriving an index across all indicators on the state of nature, nature contributions to people and quality of life associated with Nature for Nature scenarios. To generate indicators that are either common or specific across the three Nature Future value perspectives, an individual to a suite of models can be used to assess the impacts of different drivers on nature, nature's contributions to people and eventually the quality of life, either retrospectively or prospectively (Figure 4).

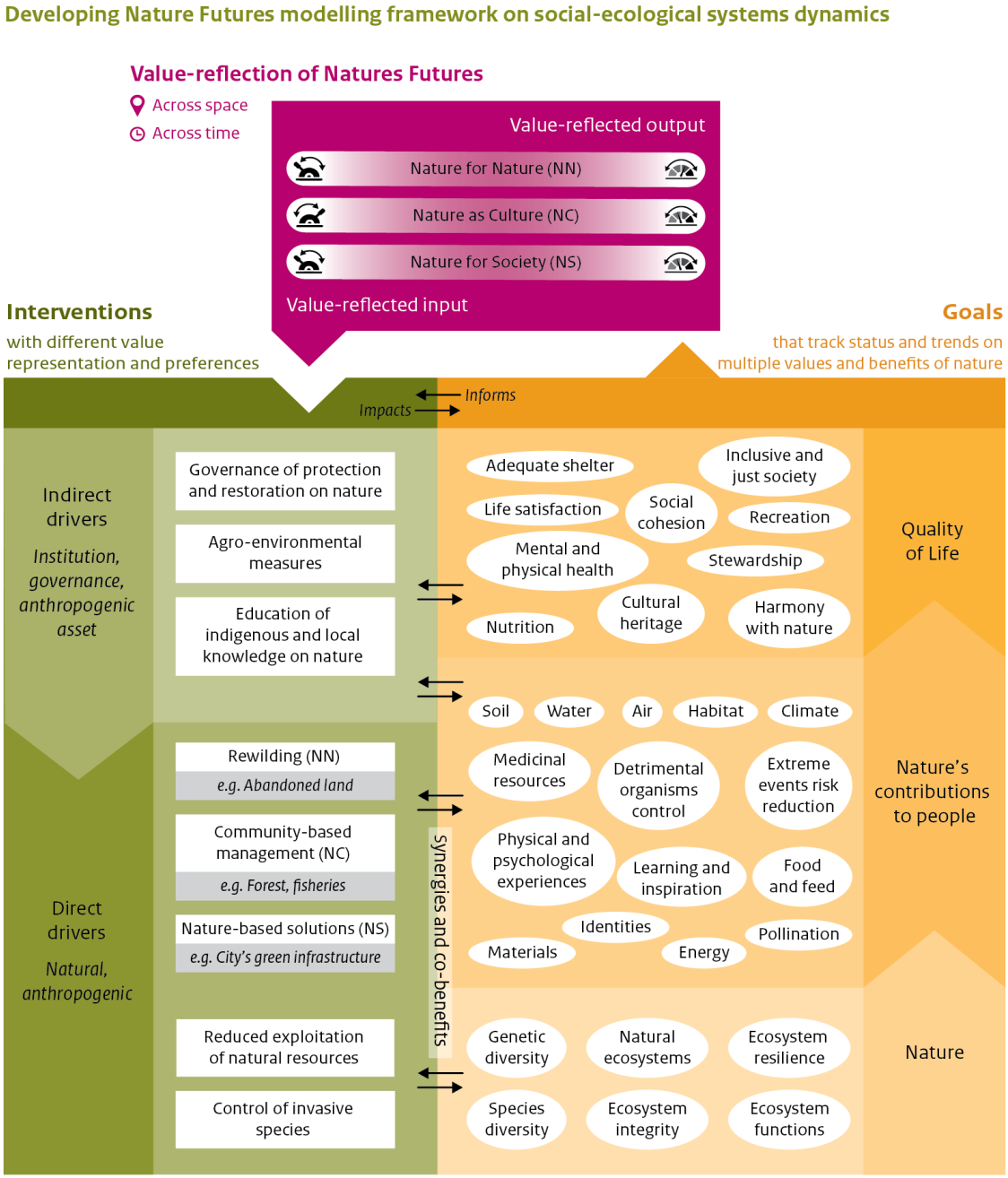


**Figure 4.** An illustrative modelling framework on the sustainable sea and land use using components of the IPBES conceptual framework with interventions on indirect and direct drivers (left panel) and goals on nature, nature's contributions to people and quality of life (right panel). The Nature Futures scenarios can combine different degrees of nature values 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 emphasize identifying synergistic interventions with co-benefits that can reinforce each other onto pathways to the Nature Futures Frontier.

### *3.3 Key remaining challenges to modelling Nature Futures scenarios*

Most modelling approaches have not yet incorporated multiple values of nature or only do so in a limited fashion (Brown et al., 2019). This is particularly true for the relational values of nature. As illustrated, integrating diverse value perspectives in modelling the NFF is essential for a more comprehensive assessment of the consequences of value-reflected decisions on nature and people. (Table 1, Figure 4).

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

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

New models are in development that incorporates feedbacks reflecting the effect of biodiversity and ecosystem services provision factors on economy and vice versa (Banerjee et al., 2020; Johnson et al., 2020). However, long term social-ecological feedbacks at large scales and incorporation of tipping points/regime shift need to be fully considered in Nature Futures scenarios to efficiently inform the policy (PBL, 2019b; Rosa et al., 2017).

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

## 4. Moving towards Nature Futures

To date, scenarios and models in environmental assessments have tended to focus on representing human impacts on ecosystems and lacked positive futures for nature and the people (IPBES, 2016; Pereira et al., 2021). Scenarios and models can integrate a broad set of the world's dynamics that can transform people and the nature (L. M. Pereira et al., 2020). To achieve this, the existing models on biodiversity, ecosystem services and social-ecological systems need to be mapped and coupled to form comprehensive frameworks that integrate potential feedbacks across them, improving the representation of globally connected social-ecological systems that exhibit cross-scale interactions (Keys et al., 2019). Furthermore, relational values of nature need to be reflected better in the models and indicators, notably improved capacity in modelling how environmental changes alter human behaviour, institutions, or culture and vice versa (Elsawah et al., 2020; O'Neill et al., 2020).

Model algorithms developed based on observed data are crucial to predicting changes into the future rigorously (Mouquet et al., 2015; Urban et al., 2016), enhancing the credibility of models. We can use

a wide range of observation data and correlation based on observed trends in drivers to forecast responses of biodiversity and ecosystems under different policy interventions (Petchey et al., 2015). High-resolution remote-sensing and other observational evidence ("big data"), jointly with advanced machine learning technologies and cloud-based computing, can contribute significantly to increasing the predictive power of changes in biodiversity and nature's contributions to people (Urban et al., 2022; Willcock et al., 2018). Making Nature Futures scenarios truly biodiversity-centric thus presents a critical challenge in biodiversity science to shift the conventional impact modelling of negative anthropogenic drivers on the environment to positive anthropogenic drivers and impacts of biodiversity on nature, and in turn, on people and society, in a full circle.

As elaborated in this paper, the NFF aims to support transformative change towards sustainable futures by placing human-nature relationships at the centre. It bridges across knowledge systems and communities of practices through continuous dialogue, creating a culture of stakeholder-driven scenarios development and their co-implementation while maintaining a minimum consistency and comparability (Lundquist et al., 2017). In the coming years, we expect that the Nature Futures approach will enable scientific and broader stakeholder communities to identify policy and management interventions that reflect diverse ways people can value nature more than we have until now. To achieve this, a participatory approach is being followed to engage stakeholders in developing narratives, engineering models and building evidence bases for solutions to conservation and sustainability issues (PBL, 2019a, 2019b; L. M. Pereira et al., 2020). This inclusive approach is meant to ensure that the information generated from Nature Future scenarios is relevant for and is used by the stakeholders to initiate and amplify necessary societal transformations. Addressing interlinkages, co-benefits and trade-offs between sectors, such as food, biodiversity, water and energy with so-called nexus approaches, will be vital to finding pathways towards achieving multiple societal goals (Liu et al., 2018; Singh et al., 2018). This work is also expected to contribute to the future assessments of IPBES on "transformative change" and "nexus", which were initiated at the eighth IPBES Plenary session in June 2021.

The ambition of Nature Futures is to help expand the integration of nature in policy-making across sectors and better link the efforts of scientists and knowledge holders to values and associated decisions for nature and people positive futures. In an era where combined global environmental changes are at play, marine, terrestrial and freshwater biodiversity is imperilled. The spread of COVID-19 has transformed social-ecological systems, pressing new norms on all societies and bringing a sense of extreme urgency to build back better and greener. The Nature Future Framework presented in this paper is expected to stimulate that development through scenarios and models that can inform the realization of multiscale policy frameworks such as the CBD Post-2020 Global Biodiversity Framework and the UN Sustainable Development Agenda, thereby bringing the world onto pathways towards more ecological, livable and just futures.

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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 discussions and post-workshop synthesis. All authors participated in workshops and contributed to co-developing concepts and approaches presented. HJK led writing and revision with the guidance of HMP. All authors improved the manuscript with comments and corrections. HJK developed figures based on input from all authors and graphical support from Sandy van Tol at PBL. All authors gave final approval for publication.

# SUPPLEMENTARY MATERIALS

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

HyeJin Kim, Garry D. 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, Kathryn K. Davies, 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

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

***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

## Appendix B. Indicators discussed on the Nature Futures Framework

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

| | | Nature for Nature | Nature for Society | Nature as Culture |
|---|---|---|---|---|
| OCEAN | | | | |
| Management | Total sustainable catch | | ↗ (1) | |
| | % fish from aquaculture | | | |
| | Level of management decision | Global | | Local |
| | Area with no-take marine protected area | ↗ (2) 30% | | |
| | Area under community-based management | | | ↗ (3) |
| State | % fish stocks depleted | ↘(All stocks) | ↘(Commercial stocks) | ↘(Culturally important stocks) |
| | % species endangered | ↘ (1) | | |
| | Status of culturally important species | ↗ | | ↗ (2) |
| | Area of wetland & mangroves | ↗ (3) | ↗ | |
| Benefit | Carbon sequestration | | ↗ (2) | |
| | Dietary needs met | | | |
| | Number of jobs | | ↗ (3) | |
| | Recreation in nature | | | |
| | Livelihoods | | | ↗ (1) |
| | Social cohesion | | | ↗ |
| LAND | | | | |
| Management | Level of management decision | Global | | Local |
| | Area under community-based management | | | ↗ (1) |
| | Area under rewilding | ↗ (2) | | |
| | Wilderness protected area | ↗ (3) | | |
| | Invasive species | ↘(4) | | |
| State | % endangered species | ↘ (1) | ↘ | ↘ |
| | Status of culturally important species | | | ↗ (2) |
| Impact | Clean water | | ↗ (1) | |
| | Carbon sequestration | | ↗ | |
| | Soil protection | | ↗ | |
| | Pollination | | ↗ | |
| | Timber provision | | ↗ | |
| | Local crops and breeds | | | ↗ (3) |
| | Sustainable bushmeat | | | ↗ (4) |
| | Dietary needs met | ↗ | ↗ | ↗ |
| | Number of jobs (ecotourism, agriculture, recreation) | | ↗ (2) | |
| | Recreation in nature | | ↗ (3) | |
| URBAN | | | | |
| Drivers | Density of city | High (1) | | Low |
| | % of people in cities | High (2) | Medium – High | Low |
| | Distribution of city SAD? | Medium | Medium | Small |
| | Remote responsibility | ↗ ↗ ↗ | | |
| | Green spaces that are self-sustained | ↗ | | |

| | | | | |
|---|---|---|---|---|
| Pressure | Air quality regulation | ↗ | ↗ (1) | |
| | Water quality regulation (waste water management) | ↗ | ↗ (2) | |
| | Community gardening | | | ↗ (2) |
| | Urban gardening | | ↗ | |
| | Green roofs / nature-based solution | | ↗ | |
| | Level of management decision | Global | | Local |
| State | Species richness (no-take species) | ↗ | | |
| | Status of culturally important species | | | ↗ |
| | Area of green spaces | ↗ Natural green spaces | ↗ Functioning green spaces (3) | ↗ Cultural green spaces |
| Impact | Number hours commute | ↘ | ↘ | ↘↘↘ |
| | Mode of commute | Mass transportation, biking | | |
| | Equity | ↗ | ↗ | ↗ |
| | Mode of entry supply | Central | Renewable | Local |
| | Accessibility to green areas | Good for large | Depends on function | Small green and close (1) |
| | Hours of nature education | ↗ Biodiversity | ↗ ES | ↗ Bioculture |

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

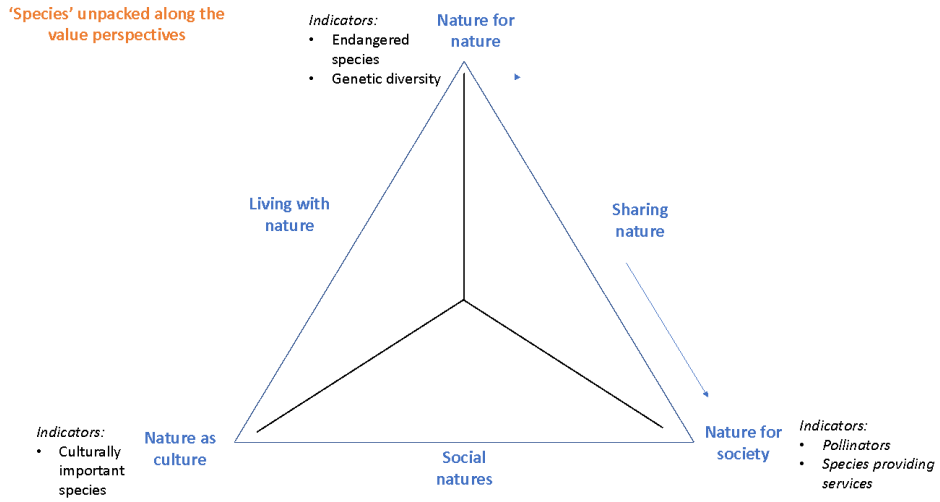
| | **Management** | **State** | **Benefit** |
|---|---|---|---|
| *Nature for Nature* | *Indicator: Protected areas*<br>Marine: WDPA - No take<br>Terrestrial: WDPA 1-3 | *Endangered sp. and habitat*<br>M: Endangered species, Coral reef cover<br>T: endangered sp., pristine forest, wetland extent<br>apex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

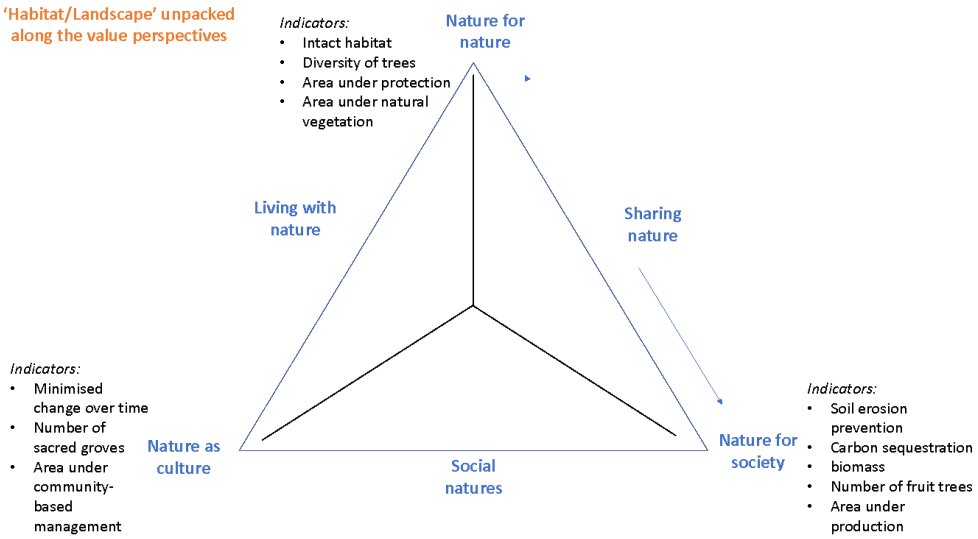
Source: Illustrative examples during the follow-on consultation post-workshops in drafting this paper

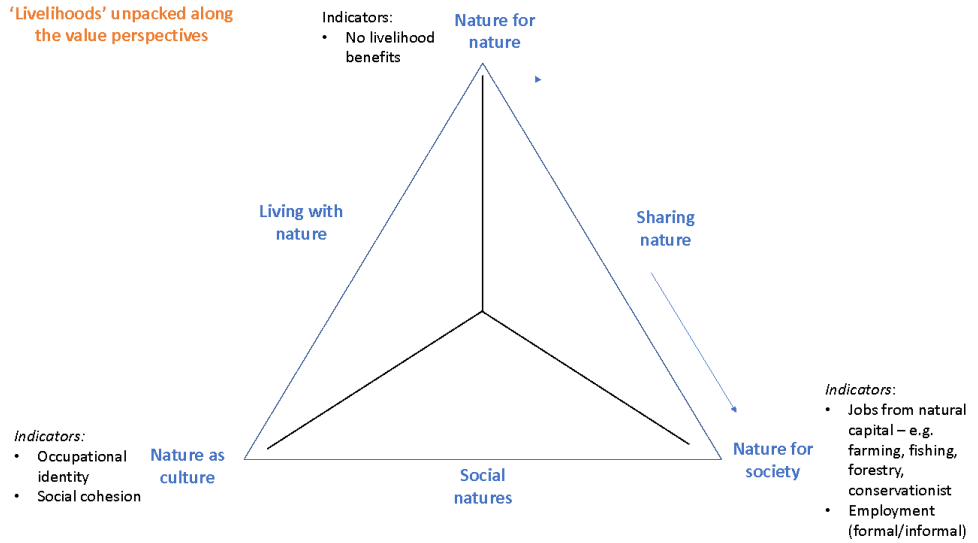
| | **Indicators**<br>- data, information and knowledge | **Nature for Nature**<br>- Rewilding Nature | **Nature for Society**<br>- Circular Economy | **Nature as Culture**<br>- Sustainable Food |
|---|---|---|---|---|
| **INTERVENTIONS**<br>Institutions<br>Governance<br>Anthropogenic asset | Projects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

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

**Appendix C. Assessing single policy using the Nature Futures Framework with indicators that measure three value perspectives** (Source: 2019 Vancouver Stakeholder Workshop(PBL, 2019a))

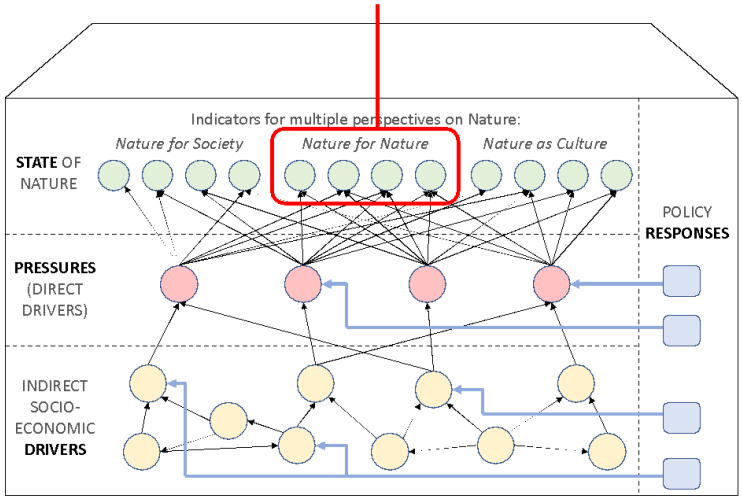


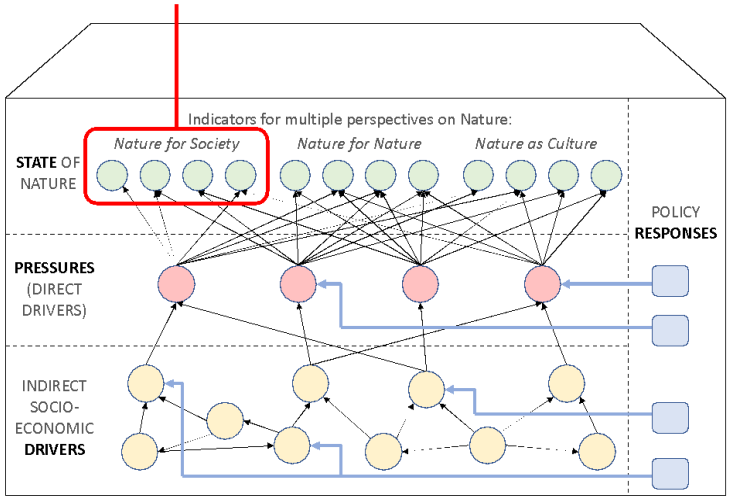



**Appendix D. Assessing systems dynamics using the Nature Futures Framework and Driver-Pressure-State-Impact-Response** (Source: 2019 Vancouver Stakeholder Workshop(PBL, 2019a))

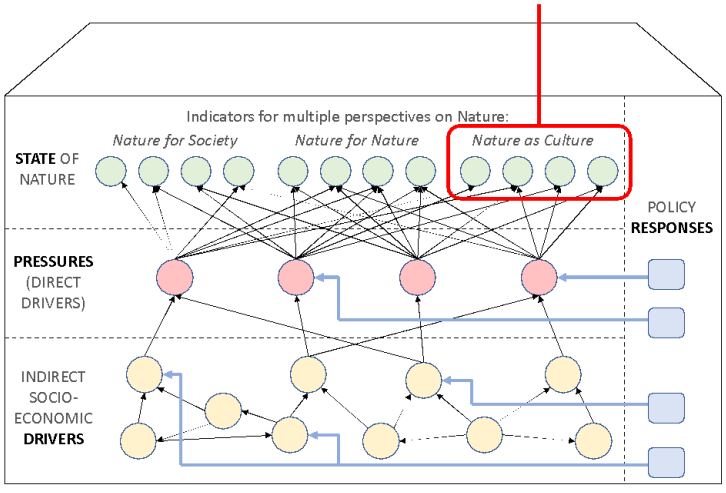
- Individual species of particular conservation concern (e.g. Red List species) ☺☺☺
- Conservation of overall species diversity ☺☺



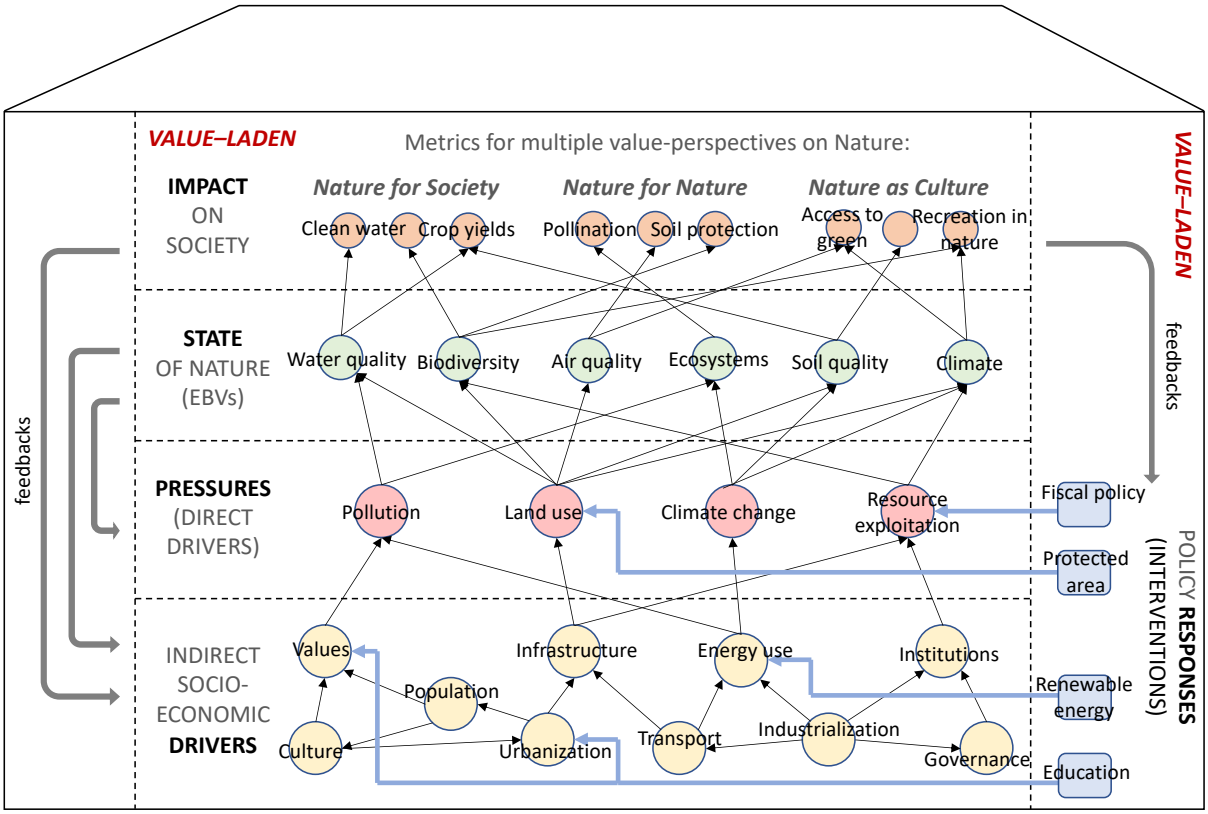

- Particular service-providing species, or groups of species (e.g. pollinators) ☺
- Overall species diversity -> maintenance of ecosystem function/services

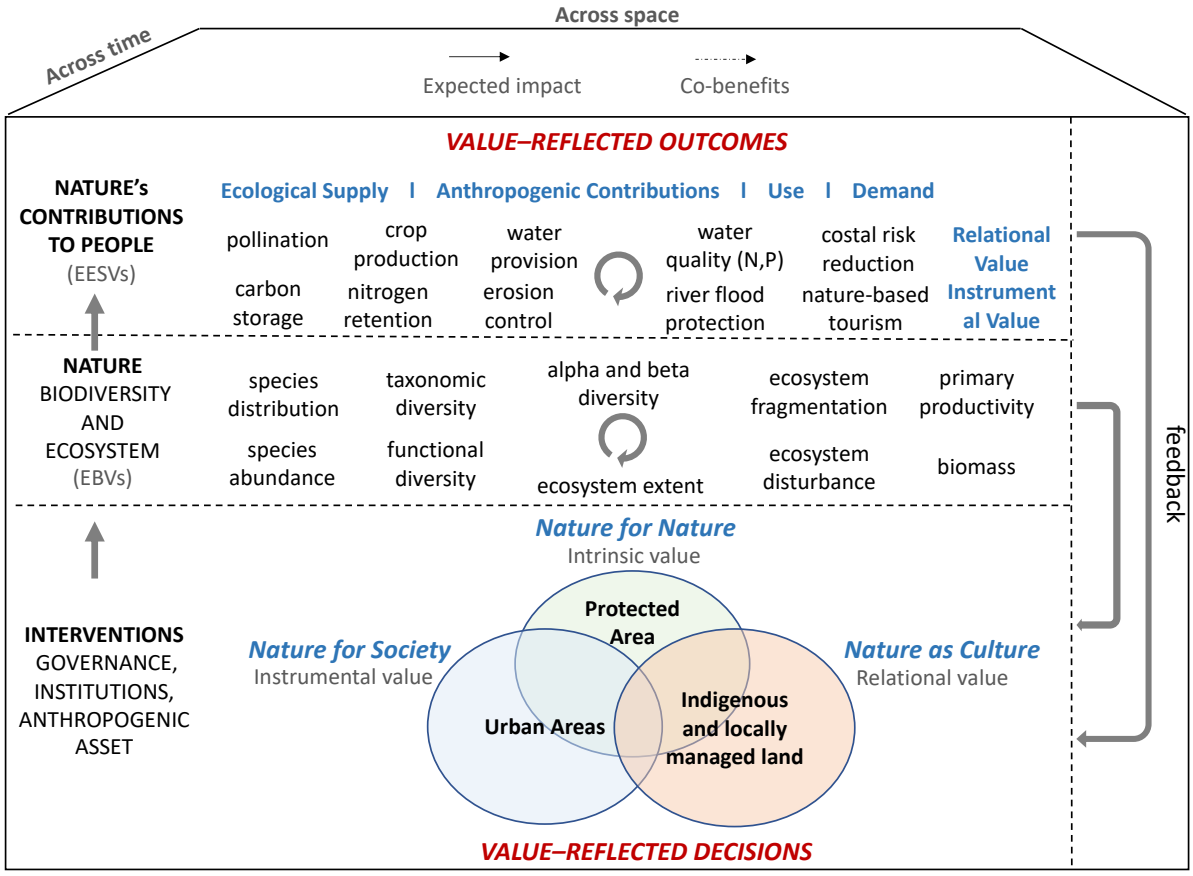



- Particular species of cultural significance
- Overall species diversity – cultural value?



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



**Appendix E. Nature Futures modellable questions assessed on novelty, feasibility, scale, policy impact** (Source: 2019 The Hague Modellers Workshop(PBL, 2019b))

***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:*<br>● Diversity: maintaining genetic diversity of crops/resilience<br>● Locally sourced: diets/food miles/supply chain<br>● Traditional culture: would maintaining a traditional diet impact biodiversity | Diversity: 4<br>(FAO cropland genetic diversity)<br>Local source: 6<br>(transport across natural boundaries., can do local region, not direct relationship between local supply and GHG footprint)<br>Traditional culture: 1<br>(possibly at very local scale) | 10 | 10 |
| *Livelihood:*<br>● Cultural identity maintained (species still exist)<br>● Influence of change/drivers | Identity: 10<br>Drivers: 10 | 5 | 8 |
| *Cultural landscapes and biodiversity*<br>● Provision of BES<br>● Resilience to drivers/climate change | Local/regional: 10 (has been done)<br>Global: 2 (how to scale up) | Local/regional: 5<br>Global: 10 | 10 |
| *Management intensity*<br>● Food production efficiency<br>● BES contributions<br>● Land sharing vs land sparing<br>● Different types of PAs<br>● Different spatial and temporal management regimes | 10<br>e.g. PREDICTS differentiate GLOBIO but many lump LU | Configuration and link to cultural landscape<br>Local: 10<br>Global 10 | 10 |
| *Leverage points for restoring and/or maintaining cultural landscapes*<br>● Agricultural subsidies for diverse agro-cultural landscapes<br>● PAs that include biocultural (Medellin) | Local/regional: 9<br>Ocean models, econometric models (have subsidies) | 5 | 7 |
| *Ecosystem benefits to people*<br>● Mental health (MH)<br>● Sense of place/identity (SoP) | MH: nature access/distance 10<br>(lots of data but not in scenarios)<br>SoP: 2 | MH: 8<br>SoP: 10 | MH: 8<br>SoP: 10 |
| *Impacts of greening of urban spaces*<br>● Accounting for green space on BES. | Local: 10<br>Global: 8 | Local: 2 Global: 10 | 8 |

***Cross-cutting***

Ranking of questions

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

Clustering of questions (possible categories):

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

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

## Appendix F. Glossary

**Co-benefits:** It 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' (IPCC, 2015; Mayrhofer and Gupta, 2016).

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

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

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

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

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

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

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

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

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

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

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

**Pathways:** Different strategies for moving from the current situation towards a desired future vision or set of specified targets. They are purposive courses of actions that build on each other, from short-term to long-term actions into broader transformation (Ferguson et al., 2013; Wise et al., 2014). The Three

Horizons approach is often used to define such pathways in future visioning processes (Sharpe et al., 2016).

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

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

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

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

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

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

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

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

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

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

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

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

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