Chapter **3**

FUTURE INTERACTIONS ACROSS THE NEXUS[1]

COORDINATING LEAD AUTHORS:
Zuzana V. Harmáčková (Czechia), Mark D. A. Rounsevell (United Kingdom of Great Britain and Northern Ireland/Germany), Odirilwe Selomane (South Africa)

LEAD AUTHORS:
Emma Marjorie Awuku-Sowah (Ghana/United Kingdom of Great Britain and Northern Ireland), Sugeng Budiharta (Indonesia), Marta Coll (Spain), Simon Hales (New Zealand, United Kingdom of Great Britain and Northern Ireland/New Zealand), Pankaj Kumar (India/Japan), David Leclère (France/Austria), Anna Metaxas (Canada, Greece/Canada), Bruno Meirelles Oliveira (Brazil/Austria), Margaret Awuor Owuor (Kenya/Switzerland), Alexander Popp (Germany), Brenda Rashleigh (United States of America), Stephanie M. Thomas (Germany), Kazuaki Tsuchiya (Japan), Grace Villamor (Philippines/New Zealand), TianXiang Yue (China)

FELLOWS:
Martin Jung (Germany/Austria), Charity Nyelele (Zimbabwe/United States of America)

CONTRIBUTING AUTHORS:
Elizabeth Diaz General (Chile/Germany), Michelle Fourie (South Africa), Angelo Fraga Bernardino (Brazil), Mcdonald Garai (Zimbabwe/South Africa), Alexandra Masako Goossens-Ishii (France/France, Switzerland), Ashanapuri Hertz (Indonesia/Sweden), Ian P. Holman (United Kingdom of Great Britain and Northern Ireland), HyeJin Kim (Republic of Korea/United Kingdom of Great Britain and Northern Ireland), Magdaléna Koudelková (Czechia), Saibo Li (China), Aline Mosnier (France), Valeria Mazzola (Italy/Germany), Christian Neumann (Germany), Carlo Rondinini (Italy), Megan Irene Saunders (Canada, Australia/Australia), Thomas M. Schmitt (Germany), Alejandrina Viesca-Ramirez (Mexico/Czechia)

REVIEW EDITORS:
Brian Klatt (United States of America), Haris Piplas (Bosnia and Herzegovina/Switzerland)

TECHNICAL SUPPORT UNIT:
Tiff L. van Huysen

1. Authors are listed with, in parentheses, their country or countries of citizenship, separated by a comma when they have more than one; and, following a slash, their country of affiliation, if different from that or those of their citizenship, or their organization if they belong to an international organization. The countries and organizations having nominated the experts are listed on the IPBES website.

THIS CHAPTER SHOULD BE CITED AS:
Harmáčková, Z. V., Rounsevell, M. D. A., Selomane, O., Awuku-Sowah, E. M., Budiharta, S., Coll, M., Hales, S., Jung, M., Kumar, P., Leclère, D., Metaxas, A., Meirelles Oliveira, B., Nyelele, C., Owuor, M. A., Popp, A., Rashleigh, B., Thomas, S. M., Tsuchiya, K., Villamor, G., and Yue, T. X. (2024). Chapter 3: Future interactions across the nexus. In: Thematic Assessment of the Interlinkages among Biodiversity, Water, Food and Health of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Harrison, P. A., McElwee, P. D., and van Huysen, T. L. (eds.). IPBES secretariat, Bonn, Germany. DOI: https://doi.org/10.5281/zenodo.13850303

Note

The Nexus Assessment chapters share a common thread of case studies highlighting Indigenous Peoples' and local communities' (IPLC) food systems. **Chapters 1** to **4**, **5.1** to **5.5** and **6** include one or more of these case studies. The case studies are presented in boxes and are distinguished by *box titles in italicized font*. Lessons learned from the common case studies are presented in **Chapter 7**, online **Suplementary material 7.1**.

Disclaimer on maps

The designations employed and the presentation of material on the maps used in the present report do not imply the expression of any opinion whatsoever on the part of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. These maps have been prepared or used for the sole purpose of facilitating the assessment of the broad biogeographical areas represented therein.

Table of Contents

Chapter 3

LIST OF FIGURES

LIST OF TABLES

LIST OF BOXES

Chapter **3**

FUTURE INTERACTIONS ACROSS THE NEXUS

EXECUTIVE SUMMARY

Understanding interactions between nexus elements in scenarios, including diverse views of the future and good quality of life, is critical in supporting policy and management actions today *(well established)* {3.1.1, 3.4.4, 3.7.1}. Scenarios are projected to have larger negative impacts in low-income regions due to trade-offs between nexus elements *(established but incomplete)* {3.4.2, 3.6.2}. Scenarios describe a range of direct and indirect drivers *(well established)*, but the interactions between these drivers play out differently at different temporal and spatial scales and for different geographic regions *(established but incomplete)*. Scenarios highlight the importance of tackling indirect drivers of biodiversity loss as these affect multiple nexus elements individually and through interactions (established, but incomplete). Future trade-offs between nexus elements may be more severe in already vulnerable and low-income regions. Climate change, for example, is projected to negatively impact biodiversity and health in developing countries through changes in food imports and prices, and subsequent impacts on agricultural systems and food availability *(established but incomplete)* {3.4.2, 3.6.2}.

Understanding of nexus interactions amongst Indigenous Peoples and local communities can enrich scenarios with alternative knowledge and value systems *(established but incomplete)* {3.1.1, 3.6.2.2] (Box 3.1, Box 3.7). Diverse visions of the future support better governance of nexus interactions leading to sustainable resource management and just outcomes for nature and people *(established but incomplete)* (Box 3.2). Knowledge co-design, co-production and sharing can lead to more inclusive future scenarios by including multiple ways of knowing *(established but incomplete)* {3.7.3}. Actions that support decolonization and strengthen Indigenous customary practices are critical for ensuring future thriving of Indigenous cultures and knowledge {3.1.2, 3.6.4}. Climate change mitigation, and its complex interactions with food, health and biodiversity, is a major concern for Indigenous Peoples and local communities {3.1.2, 3.4.2, 3.7.3} **(Box 3.2, Box 3.4)**. Strengthening the local context in scenario building and analysis is crucial in capturing how biodiversity, nature's contributions to people and social-ecological dynamics contribute to diverse knowledge systems *(established but incomplete)* {3.7.3}.

Scenarios that maintain current trends into the future continue to place biodiversity at risk and have negative implications for other nexus elements and nature's contributions to people *(well established)* {3.7.1}. These scenarios indicate that declines in biodiversity will continue unless rapid, integrated and transformative change is undertaken across the nexus *(established but incomplete)* {3.2.1, 3.3.1, 3.4.1, 3.5.1, 3.6.1}. Scenarios that maintain current trends into the future (Business-as-Usual scenarios) are broadly negative across the nexus elements {3.2.1, 3.3.1, 3.4.1, 3.5.1, 3.6.1, 3.7.1}, leading to impacts from climate change {3.2.1}, malnutrition {3.4.2}, heat-related human mortality and morbidity, infectious diseases and mental health {3.5.1}. Increasing water and food demand are projected to further undermine water quality, ecosystem habitats and health {3.3.1, 3.4.1}. Business-as-usual scenarios often assume expansion and intensification of cropland, pastures and fisheries, with detrimental impacts on biodiversity caused by habitat conversion and overexploitation, greenhouse gas emissions, increasing water withdrawals and pollution *(well established)*. Alternatively, scenarios that fail to meet food demand result in negative impacts on health through inadequate nutrient supply *(well established)* {3.7.1}. Sustainable production and consumption and a focus on issues of equity and competing demands would reverse biodiversity loss *(established but incomplete)* {3.1.2, 3.2.2, 3.2.3, 3.2.4, 3.4.4, 3.6.2} **(Box 3.2, Box 3.3)**.

Scenarios exploring expansion of nature conservation deliver positive outcomes for all nexus elements when planned in an integrated and just manner *(well established)* and coupled with broader measures such as climate change mitigation, changes in food production, equitable consumption and sustainable management *(established but incomplete)* {3.2.3.3}. Expanding nature conservation can have potential negative impacts on other nexus elements *(established but incomplete)*, notably food security and nutrition *(well established)* {3.2.3.3}. However, nature conservation can be positive when planned in an integrated and just manner *(well established)*, considering co-benefits and minimizing the trade-offs with other nexus elements across realms and spatial scales *(established but incomplete)* {3.2.3.3}. Planning future protected areas would benefit from an integrated view that maximizes synergies across the nexus and considers issues of equity and competing demands, so that additional areas are

sufficient, effective and implementable *(established but incomplete)* {3.2.3.3}.

Scenarios of active marine ecological restoration have positive effects on food and climate change *(well established)* {3.2.3.3}. Scenarios of terrestrial ecological restoration that need more land area have been shown to require food system transformation *(established but incomplete)*. The Kunming-Montreal Global Biodiversity Framework target 2 states that at least 30 per cent of the total area of degraded habitats should be under restoration by 2030. Achieving this target will require careful planning to minimize competition with food production and bioenergy provision, but would have benefits for biodiversity, climate change mitigation and adaptation, improve water quality and support nature conservation. Trade-offs between ecological restoration and nature protection and the implications for other nexus elements, such as food, highlight the need for a holistic approach to addressing biodiversity loss *(well established)* {3.2.3.7}.

Increased future freshwater demand for food production and other uses can have negative consequences for biodiversity, especially in the context of future climate change *(established but incomplete)* {3.3.2, 3.3.3}. Scenarios emphasize the difficulty of reaching win-win solutions in the water sector that are positive for all stakeholders. However, various systematic approaches have been proposed for water management, such as nature-based solutions, to achieve positive outcomes *(established but incomplete)* {3.3.2, 3.3.3, 3.3.4}.

Transformative change across the food system is central to unlocking co-benefits for biodiversity, nutritional health, climate change and water *(well established)*. The food system is important in many scenarios evaluating biodiversity impacts within the nexus for both terrestrial and marine realms *(well established)*. For example, national scale increases in food imports have been shown to cause indirect land-use change, such as deforestation, in exporting countries *(established but incomplete)* {3.2.3, 3.2.4}. The current agricultural area can potentially feed future human populations in the medium to long-term while reducing greenhouse gas emissions and water pollution *(well established)* {3.4.3.1} through sustainable agricultural practices and improving nitrogen use efficiency from the current 35 to 44 per cent to 70 to 80 per cent, combined with a reduction in the over-consumption of meat and optimal crop food-feed ratios *(well established)* {3.4.3.1}. Positive food system scenarios also include sustainably managed fisheries, healthy diets that are less resource intensive and distributing food more equitably *(well established)* {3.4.2, 3.4.3}.

There are clear co-benefits to nutritional health from widespread adoption of a less meat intensive diet, which could provide sustainable healthy diets for 10 billion people in 2050, preventing 19 to 24 per cent of total deaths per year among adults caused by insufficient food and unhealthy diets, without overstepping global biophysical limits *(established but incomplete)* {3.4.2}. Reductions in livestock numbers due to reduced intake of animal-based foods would reduce the demand for plant proteins such as soy used for animal feed and the land area used for pasture *(established but incomplete)* {3.4.2}. However, increases in the production of plant-based proteins in tropical regions could have negative impacts on biodiversity *(established but incomplete)* {3.4.2}.

Foods from freshwater and marine environments can contribute positively to health, climate change mitigation and adaptation and biodiversity conservation *(well established)* {3.4.3.2}. Fisheries scenarios show that climate change and the choice of management practices could negatively affect marine ecosystems and the long-term availability of marine food *(well established)* {3.4.3.2}. Sustainable fishing practices, including the use of efficient fisheries restricted areas, would ensure sustainable production *(well established)* {3.4.3.2}. Sustainable mariculture is a potential alternative to continuing deteriorating fish stocks and is expected to grow in the future as an important source of nutrition *(established but incomplete)* {3.4.3.2}, although some regions will face greater climate change challenges. Countries with less affected maricultural sectors could add stability through trade *(established but incomplete)* {3.4.3.2}.

Scenarios show that land-use change influences the exposure of humans to zoonotic hazards. The distribution of several vector-borne diseases is projected to shift towards higher latitudes and altitudes under climate change scenarios *(established but incomplete)* {3.5.2}. Changes in biodiversity, land-use and land cover, and social behaviour will shape future disease emergence {3.5.2.1}. New mammal assemblages and viral evolution hotspots are projected to occur in areas of high human population density, which could act as starting points for newly emerging zoonoses *(established but incomplete)* {3.5.1, 3.5.2}. However, these effects will vary locally depending on the implementation of individual and public health prevention measures {3.5.1, 3.5.2}. Some non-native arthropod disease vectors may colonise new locations under warmer temperatures. For other vectors of human diseases, the geographic extent of habitable regions in some localised terrestrial landscapes could decrease with a warming climate *(established but incomplete)* {3.5.2}.

Urban green and blue space can have positive effects on mental and physical health and other nexus elements (climate change mitigation, food production and water regulation), including the improvement of local micro-economic conditions

and social cohesion *(established but incomplete)* {3.5.3}. As land-use, precipitation, temperature and extreme weather patterns change, opportunities for urban and coastal green spaces to support mental health and physical exercise are projected to diminish {3.5.3}. Under high-end climate scenarios, cyanobacterial and algal blooms would elicit marine biodiversity imbalances that downgrade the recreational value of fisheries and the support functions of marine and coastal ecosystems *(established but incomplete)* {3.3.1, 3.5.3}.

Scenarios indicate the importance of early climate change mitigation actions, with further delays expected to be more costly. Delay will also require land-based carbon dioxide removal at large scale that would increase competition for land and water *(well established)* {3.6.3}. Delays in mitigation actions will cause greater trade-offs across the nexus, jeopardizing water supply, biodiversity and habitat restoration as well as food security *(well established)* {3.6, 3.6.3}. A holistic portfolio of integrated measures across the nexus would contribute to climate change mitigation while also benefiting sustainable development *(established but incomplete)* {3.6.3}. For example, ecosystem restoration, sustainable production and consumption, dietary and energy transitions promise benefits across multiple nexus elements *(well established)* {3.6.3}. The ocean is a major climate change mitigator with many solutions focusing on the placement of excess carbon in deep water, but these solutions are still far from implementation and knowledge is lacking about potential impacts on biodiversity and food *(established but incomplete)* {3.6.3.2}. Scenarios of continuation of current trends for climate change mitigation (and adaptation) tend to be more costly and less just than scenarios based on a holistic portfolio of integrated measures across nexus elements *(established but incomplete)* {3.6.3}.

Human-induced climate change is expected to impact the entire nexus, becoming worse over the coming decades *(well established)* {3.6.1, 3.6.2}. Adaptation will be key to addressing the multiple hazards arising from climate change *(well established)* {3.6.3, 3.6.4}. Climate change is projected to be an increasingly important driver of biodiversity and ecosystem change affecting genetic, species and ecosystem levels *(well established)* {3.2.1, 3.3.1, 3.4.1, 3.5.1, 3.6.2}. Projected impacts vary substantially in different parts of the world owing to variations in the different drivers of biodiversity change and their time scales *(established but incomplete)* {3.6.2}. Climate change adaptation actions can have antagonistic effects (maladaptation) as well as co-benefits for other nexus elements *(established but incomplete)* {3.6.2}. There is a growing gap between countries' preparedness for climate change and the actual adaptation measures needed to respond to increasing climate risks *(established but incomplete)* {3.6.4}.

Scenarios cluster into six nexus scenario archetypes that reflect different relationships between the nexus elements and their positive and negative outcomes *(established but incomplete)* {3.7.1} (Figure 3.6). The *nature-oriented nexus* archetype has high benefits for biodiversity and is broadly positive for the other nexus elements. *Balanced nexus* is also broadly positive across nexus elements, especially for food and health, but less so for biodiversity, water and climate change, reflecting elements of sustainable use and nature conservation goals. *Conservation first* is more positive for biodiversity than *balanced nexus* but has an impact on food, and smaller negative impacts on water and health, reflecting the effects of terrestrial protected areas on food production and nutritional health. The *climate first, food first and nature overexploitation* archetypes are all negative for biodiversity. Climate first is strongly negative for food, but strongly positive for addressing climate change reflecting land competition arising from climate change mitigation scenarios. *Food first* is strongly positive for food, but negative for the other nexus elements, except health, arising from co-benefits with nutritional health. *Nature overexploitation* has negative impacts across all nexus elements, although less so for water, and represents economy first scenarios and some scenarios of continuation of current trends into the future, with strong climate change impacts. The archetypes with positive outcomes for different nexus elements *(nature-oriented nexus, balanced nexus)* have flexible and well-functioning institutions, inclusive decision-making, strong pro-sustainability and environmental regulation, sustainable consumption and production, and inclusive approaches to economic development {3.2.1, 3.2.2}.

The nexus scenario archetypes have different implications for the achievement of policy goals, such as the Sustainable Development Goals, the Kunming-Montreal Global Biodiversity Framework and the Paris Agreement *(established but incomplete)* {3.7.1, 3.7.2}. Archetypes that are positive for biodiversity, and have fewer trade-offs with the other nexus elements, are also broadly positive for the Sustainable Development Goals. Climate change mitigation policy that would contribute to the Paris Agreement is more effective in future scenarios that minimize trade-offs across the nexus elements. Better connecting food and climate change policy would have beneficial outcomes in achieving multiple Sustainable Development Goals, the Kunming-Montreal Global Biodiversity Framework goals and the Paris Agreement *(established but incomplete)* {3.7.1, 3.7.2}. However, not all archetypes have positive outcomes across the Sustainable Development Goals. Sustainable Development Goals 1 (no poverty) and 10 (reduced inequalities) are largely negative across all archetypes, indicating that even the nature-oriented scenario archetypes inadequately include actions that address poverty and social inequalities. Sustainable Development Goal 5 (gender equality) is absent from all scenarios and archetypes, which is a significant knowledge gap amongst the nexus scenarios. Sustainable Development Goals 16 (peace, justice and strong institutions) and 17 (partnerships for the goals) are missing in the nature-negative archetypes, although these goals are critical prerequisites for most response options *(established but incomplete)* {3.7.1, 3.7.2}.

Knowledge gaps include the need for more scenarios covering interactions between the nexus elements and advances in scenario methods to better represent them *(established but incomplete)* {3.7.6}. The complexity of health and disease, including projected changes in biodiversity, socio-economic determinants of health and public health actions, is inadequately depicted in scenarios *(unresolved)* {3.5, 3.7.6}. Nature-oriented scenarios that are also plausible in terms of implementation, especially policy implementation, are lacking *(established but incomplete)* {3.7.6}. Further development and application of quantitative, integrated modelling tools, qualitative methods and approaches to learn from and include Indigenous and local knowledge would advance understanding of the role of biodiversity within the nexus *(established but incomplete)* {3.7.6}. Scenarios are lacking for polar regions, the open and deep oceans and tropical regions with missing scientific data monitoring, and the further development of scenarios that better link processes across realms would support the recognition of co-benefits between sectors and their impacts *(established but incomplete)* {3.7.6}. There are very few quantitative scenarios with a direct focus on health *(established but incomplete)* {3.5, 3.5.1, 3.7.6} with health more commonly addressed through the lens of other nexus elements {3.7.6}.

3.1 INTRODUCTION

3.1.1 Scope of this chapter

Scenarios and models provide a means for exploring uncertainties about how different drivers of change might develop in the future and how those changes might impact the interconnections among the nexus elements. They can therefore help to anticipate change and foster synergistic and collective action that benefits multiple elements of the nexus (IPBES, 2016). Negative trends in the state of nature and its contributions to people are mostly projected to worsen in the coming decades, albeit unevenly between different regions, because of indirect and direct drivers playing out differently across geographies. Direct drivers, such as land and sea use, direct exploitation (i.e., harvesting of plants and animals), climate change, pollution and the spread of invasive alien species (Díaz *et al.*, 2019), that have predominated in the past 50 years will continue to play an important role in the future, increasingly driving further biodiversity and NCP decline (Díaz *et al.*, 2019). These direct drivers are underpinned by a multitude of societally mediated, indirect drivers such as economy and trade, culture, demography, institutions and governance systems among others (Díaz *et al.*, 2019).

Many previous scenario studies address the impacts of direct and indirect drivers on individual sectors such as agriculture, forestry, fisheries and water. However, such studies often overlook the interactions between sectors, which may result in misinterpretation of patterns, directions and magnitudes of impact on human and environmental systems (P. A. Harrison *et al.*, 2016). Interactions play out in different ways (directions and magnitudes) in different regions and in different scenarios (P. A. Harrison *et al.*, 2016; J. Li *et al.*, 2021; J. Liu *et al.*, 2018). The discrepancies are particularly pronounced for indicators such as food production and water exploitation, which are highly influenced by other sectors and by local abundance of resources. Furthermore, the discrepancies are greater under scenarios of indirect drivers than under direct drivers, such as climate change scenarios, and at the sub-regional rather than regional scales (P. A. Harrison *et al.*, 2016).

Nevertheless, scenarios are increasingly taking a more integrated approach to evaluate the impacts of policies and decisions across multiple nexus elements, as well as the effects of interacting direct and indirect drivers, to support policy design across sectors (P. A. Harrison *et al.*, 2023). This includes incorporating wider knowledge systems and world views within scenarios, including Indigenous and local knowledge (ILK), which has previously been neglected (Lam *et al.*, 2020) **(Box 3.1)**. Scenario studies are therefore vital to provide evidence for the integrated solutions that will be needed to collectively meet international policy goals, such as the Sustainable Development Goals (SDGs), the Kunming-Montreal Global Biodiversity Framework and the Paris Agreement.

This chapter synthesizes evidence from available scenario studies that consider future interlinkages between biodiversity, water, food, health and climate change, and their drivers, in order to answer the policy-relevant questions from **Chapter 1 (section 1.1.3)**: how might the nexus elements and interdependencies change in the future, and what pathways and scenarios could lead to sustainable futures that address the nexus elements synergistically with minimal trade-offs?

To do this, evidence is synthesized from the scientific literature, science-policy reports and Indigenous Peoples' and local communities' (IPLC) visions and scenarios, where available, to capture plural knowledge systems, including ILK. (For example, the 7th Generation Principle embodies the responsibility that present-day decisions lead to a sustainable world for seven generations into the future and dates back to the Great Law of Peace of the Haudenosaunee Confederacy.) To be included in the analysis, studies need to consider interactions between at least three of the nexus elements of biodiversity, water, food, health and climate change.

In total, 52 studies containing 186 scenarios were reviewed, identified through a structured keyword-based search and snowball sampling (for detailed information on the review process see the associated data management report).[2]

The individual scenarios (as the unit of analysis) were systematically analysed to evaluate the impact of each nexus element on the other elements, which led to the creation of six nexus scenario archetypes. Each archetype comprises a set of individual scenarios (minimum of 20 scenarios in each archetype) that have similar characteristics in terms of drivers and outcomes regarding nexus interactions. The archetypes are presented in the synthesis **section 3.7.2**.

2. The data management report for the scenarios review (https://doi.org/10.5281/zenodo.13913205).

Box 3 1 **African Biodiversity Network Indigenous Futures Thinking Dialogue.**

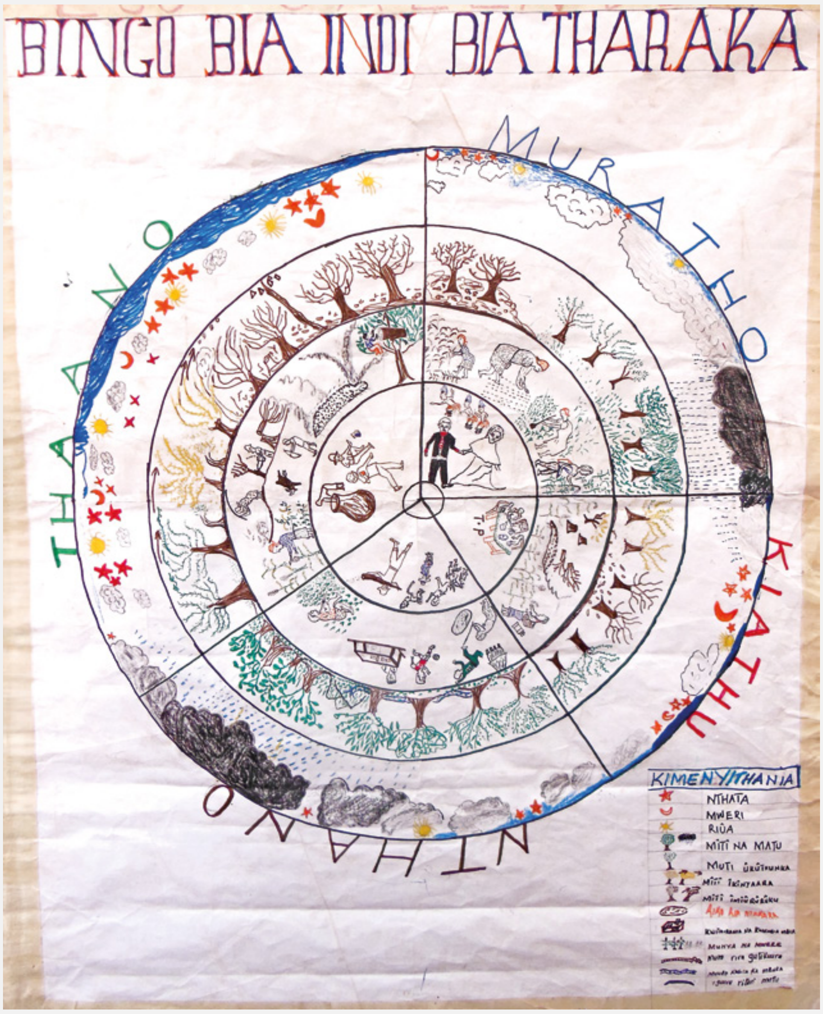


Figure 3 1 **Eco-cultural calendar for Tharaka Nithi, Kenya.**

Ecocultural calendars are a strong community research tool that covers aspects of the past, present and future and can support a process to revive a whole socio-ecological system, as they embrace the whole “universe”. The picture was taken under the collaboration between SwedBio and African Biodiversity Network, together with the Institute for Culture and Ecology and the communities of Kivaa and Tharaka, Kenya, in contributing to the piloting of the Multi Evidence Base Approach.

Source: (Tengö *et al.*, 2021) – Photo credit: Pernilla Malmer; permission for use granted by SwedBio.

Box 3 1

Indigenous and local knowledge embodies the wisdom gathered over centuries by communities living with and governing biodiversity in their everyday realities. This knowledge also guides them in envisioning their futures and navigating through unforeseen events and disruptions, such as the local impacts of climate breakdown and biodiversity loss, conflicts and socio-political change. The Indigenous futures thinking dialogue process, undertaken as a collaboration between the African Biodiversity Network, Institute for Sustainable Development in Ethiopia, Institute for Culture and Ecology in Kenya, Groupe De Recherche et d'Action pour le Bien-être au Bénin in Benin and SwedBio, supported communities in strengthening their plans and visions for their future based on their earlier experiences of community dialogues, eco-cultural mapping and calendars. As part of this dialogue, community walking workshops took place in three communities across Benin, Kenya and Ethiopia. Additionally, elders, women, men and youth from the communities of Boru Selassie in Dessie, Ethiopia; Kivaa in Eastern Kenya; and Kotan-Segbe in Sado – Avrankou, Benin were actively engaged in the local dialogue (Mburu, 2016; Tengö *et al.*, 2021).

The dialogue was a community-centred process to address challenges and develop visions for the future of the community based on their own knowledge, experiences and methods. Eco-cultural mapping and calendars are participatory tools for Indigenous futures thinking that connect past, present and future. They aim to reveal the deep geography, cultural vision and meaning of a territory, while building a collectively agreed vision of the relations of different elements that interact in the territory over time.

The Indigenous futures thinking dialogue also aimed to bridge across different knowledge systems from Indigenous Peoples and local communities, academia, government, community-based organisations, women and youth groups. Activities undertaken during the dialogue were geared towards building communities' confidence and solutions to coping with emerging issues and challenges such as COVID-19, locust outbreaks and climate change.

The dialogue identified the many challenges faced by the three communities: the erosion of ILK, loss of knowledge, weakened customary governance and culture, disconnect between the youth and the elders and between people and their places and histories. The dialogues allowed communities to discuss what they wanted to keep, what needs to change, and innovations and pathways forward to realise change. At the core of the discussions in the three communities was the conservation or restoration of critical ecosystems, revitalisation of customary governance and the potential for strengthening customary law, conflict resolution mechanisms and ceremonies to address the challenges they are experiencing. Storytelling, cultural practices, ceremonies and rituals are embedded components of enacting visions of the future. Discussions also focused on intergenerational knowledge transfer and re-connecting youth to their traditions, values and culture. The dialogues also discussed the rights of Indigenous Peoples over their lands, territories and resources, rights to continue their customary sustainable practices and their right to self-determination. The experiences included examples of partnership and collaboration with local authorities and actors.

3.1.2 Overview description of scenarios, scenario approaches and methods

Scenarios are representations of plausible futures for one or more components of a system (IPBES, 2016). The scenario approach is important to help decision-makers understand future feedbacks and uncertainties across the nexus, and in some cases in assessing the effects of policy decisions themselves (i.e., in policy scenarios) (Rounsevell *et al.*, 2021). The IPBES Methodological Assessment on Scenarios and Models of Biodiversity and Ecosystem Services (IPBES, 2016) identified four broad types of scenarios and related phases of the policy process **(Figure 3.2)**. Exploratory scenarios are often used to set agendas, and they project plausible future trajectories without prior commitment to a goal. Target-seeking scenarios are used to design processes to achieve a desired and identified outcome (a vision or a goal). Policy screening scenarios evaluate the implementation stage, and how multiple policies perform in relation to a desired outcome. Finally, retrospective policy evaluation scenarios review past policies and assess how far a given policy is from the intended outcome.

Of the 186 assessed scenarios, most were exploratory scenarios that showed positive and negative future impacts on the nexus elements. Others were target-seeking scenarios that demonstrated how different combinations of response options that take account of interlinkages among the nexus elements enable a transition to sustainable futures. The latter scenarios provide valuable knowledge for linking to chapters 4 to 6, which focus on response options.

Scenario studies are assessed across spatial scales (from local to global) and for different geographies (across biomes, climatic zones and the IPBES world regions). Out of the 186 assessed scenarios, 59 per cent covered the terrestrial realm and 41 per cent the marine realm, respectively. 57 per cent of the scenarios focused on the global scale, while 27 per cent covered the regional scale, 6 per cent the national scale and 10 per cent the local scale. Local and regional scenarios focused mainly on Europe, then Asia-Pacific and the Americas. Connections between regions are also assessed, such as through telecoupling (Hull & Liu, 2018; J. Liu *et al.*, 2013). This includes, for example, the role of global trade in indirect land-use change, the role of transboundary water management, and the role of climate

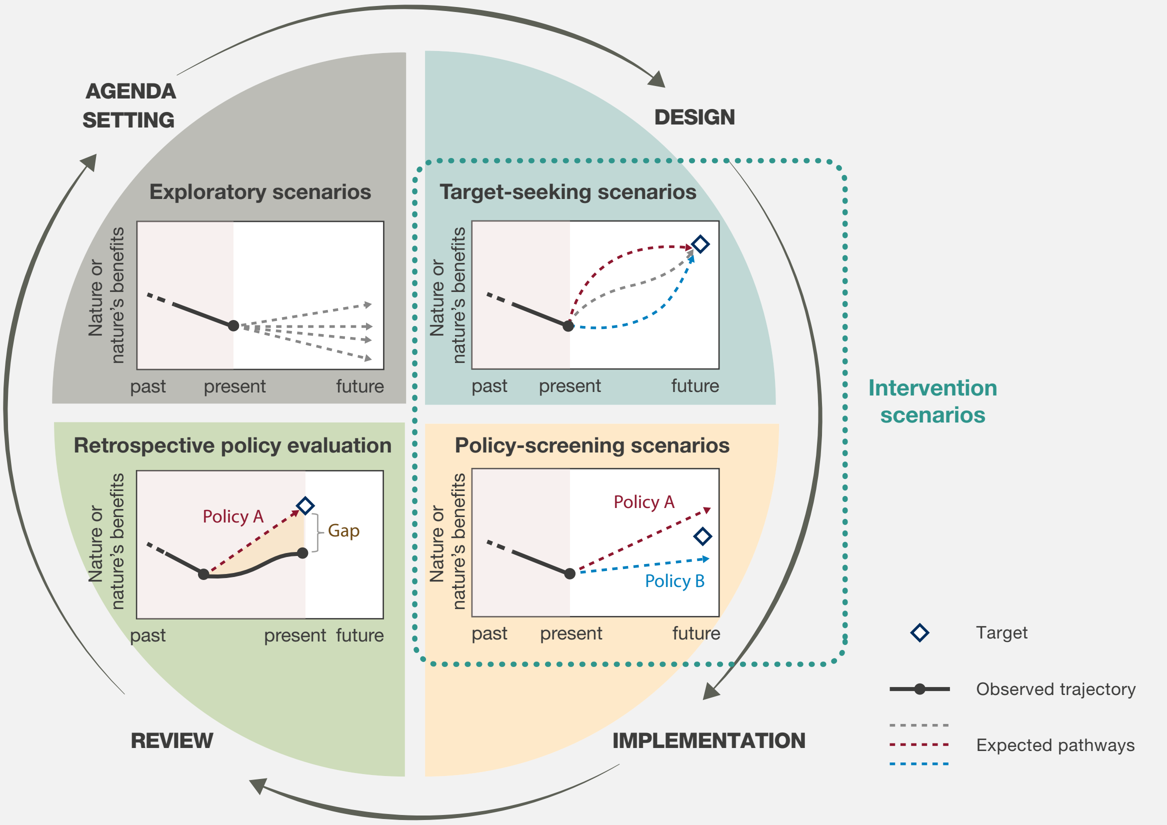


Figure 3 2 **Types of scenarios and the four major phases of the policy cycle.**

Policy cycle phases are indicated by the labels and grey arrows outside the coloured quarters of the circle. In exploratory scenarios, the dashed lines represent different plausible futures, often based on storylines. In target-seeking scenarios (also known as normative scenarios), the diamond represents an agreed-upon future target and the coloured dashed lines indicate scenarios that provide alternative pathways for reaching this target. In policy-screening scenarios (also known as ex-ante scenarios), the dashed lines represent various policy options under consideration. In retrospective policy evaluation (also known as ex-post evaluation), the observed trajectory of a policy implemented in the past (solid line) is compared to scenarios that would have achieved the intended target (dashed line). Source: IPBES (2016).

and oceanographic events such as El Niño and La Niña outside the Pacific region.

The future is considered through the lens of three time horizons: the short, medium and long-term. Short-term refers to 2030, consistent with the targets of the SDGs and other regional policy targets (e.g., the European Union Biodiversity Strategy). Medium-term refers to 2050, consistent with the CBD 2050 Vision for Biodiversity. Long-term refers to the end of the 21st century and is needed to capture scenarios with long-term drivers such as climate change. There is, moreover, an important body of scenario literature that is independent of time. This includes, for example, scenarios of protected areas, dietary changes or marine protected areas that explore the consequences of these management interventions or societal choices on biodiversity without specifying when these changes will happen in practice. These studies are included since they still refer (even abstractly) to some (undefined) point in the future, and because they can add important insights into interrelationships between the nexus elements.

Scenarios are often clustered into scenario families that have similar underlying storylines, assumptions and trends in drivers of change, often called *scenario archetypes* (IPBES, 2016, 2018b). This clustering into scenario types facilitates comparisons between a large number and range of different studies (Sitas *et al.*, 2019). Examples of common scenario archetypes include global sustainable development scenarios and business-as-usual (BAU) scenarios that represent the continuation of current trends into the future and track the future outcomes of staying on the current course of action/inaction (IPBES, 2016). The Nature Futures Framework: A flexible tool to support the development of scenarios and models of desirable futures for people, nature and Mother Earth (NFF) is an example of a tool that can be used to cluster scenarios in a way that is focused on the relationship between biodiversity and people by describing three different value perspectives: those emphasizing intrinsic values (nature for nature), instrumental values (nature for society) and relational values (nature as culture/one with nature), similarly to other available value frameworks such as the Life Framework of Values from the IPBES Methodological Assessment Regarding the Diverse Conceptualization of Multiple Values of Nature and its Benefits, Including Biodiversity and Ecosystem Functions and Services (Values Assessment) (Pascual *et al.*, 2023; Raymond *et al.*, 2023). The NFF is a flexible tool to support the development of scenarios and models of desirable futures for people, nature and Mother Earth (Pereira *et al.*, 2020). The framework is described in more detail in **Box 3.2**.

Assessing the implications of future scenarios for the nexus requires modelling and non-modelling tools that are capable of holistic, integrated assessment. Quantitative modelling tools are useful in exploring the impacts and interlinkages between nexus elements for alternative scenarios and in defining goals and pathways to desirable futures. There are many tools for this purpose including integrated assessment models (e.g. P. A. Harrison *et al.*, 2018), coupled simulation models such as socio-ecological or socio-economic models (e.g. Rabin *et al.*, 2020), general ecosystem models (e.g. Harfoot *et al.*, 2014), agent-based models (e.g. Brown *et al.*, 2022), and other fully-coupled assessment frameworks based on consistent, scalable and regionally-transferable platforms (e.g. Henry *et al.*, 2022; Johnson *et al.*, 2019) that operate at different geographic scales from local to global (Tittensor *et al.*, 2021). However, all modelling tools have their limitations, and it is important to understand these limitations, the assumptions that underlie the models and scenarios, and associated different types of uncertainties when interpreting their outputs. This includes how uncertainties play out differently over short, medium and long timescales and the role of feedbacks (particularly social feedbacks), as well the need to build on multiple knowledge systems including ILK (Koven *et al.*, 2022; Lyon *et al.*, 2022; Rounsevell *et al.*, 2021). The use of ensemble modelling has been used to consider such uncertainty (e.g., Lotze *et al.*, 2019).

Many qualitative methods also exist (Capitani *et al.*, 2019) for exploring scenarios, which can be highly valuable for understanding interconnections among nexus elements and their relation to policy and management options (Beck *et al.*, 2019). Such methods are particularly useful for exploring aspects that are currently poorly represented in models, such as governance, societal and cultural drivers, as well as wider world views, including ILK, through participatory scenario development (Fulton *et al.*, 2015).

Of the 186 assessed scenarios, most were researcher-led and did not often utilize participatory approaches, including ILK. Most scenarios were based on modelled trends up to 2050 – 2100 for BAU or for the Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs) in analysing the impacts of socio-economic and climate change.

Box 3 2 A description of the Nature Futures Framework: A flexible tool to support the development of scenarios and models of desirable futures for people, nature and Mother Earth.

The Nature Futures Framework (NFF) is a scenario and modelling framework that was developed in response to the recommendations in the IPBES Methodological Assessment Report on Scenarios and Models of Biodiversity and Ecosystem Services (IPBES, 2016). The NFF fills a gap as a flexible tool for developing desirable future scenarios for people and nature centred around their diverse relationships to identify and inform context- and place-specific policy options that are locally relevant and can contribute to biodiversity conservation and good quality of life (IPBES, 2023b).

The NFF presents three main value perspectives on people's relationship with nature: nature for nature (intrinsic values), nature as culture/one with nature (relational values), and nature for society (instrumental values) **(Figure 3.3)** (Pereira *et al.*, 2020). The NFF recognizes that these value perspectives are not mutually exclusive of each other but can overlap and reinforce each other. By making diverse nature values explicit in developing future visions and generating evidence for decision-making, a broader range of nature's contributions to people is identified and considered while rightfully acknowledging nature's right to thrive on its own (Harmáčková *et al.*, 2023; H. Kim *et al.*, 2023). Furthermore, the NFF promotes the integration of diverse knowledge systems, including from Indigenous Peoples and local communities (IPLC) (Tengö *et al.*, 2014). By doing so, the NFF aims to encourage societies to envision desirable and realizable futures where people and nature co-exist in harmony, building on existing good practices and evidence. The future visions, narratives and modelled evidence are expected to engage a broad range of stakeholders from societies to catalyse the transformation required to achieve sustainable futures (Durán *et al.*, 2023; IPBES, 2023b).

Box 3 2

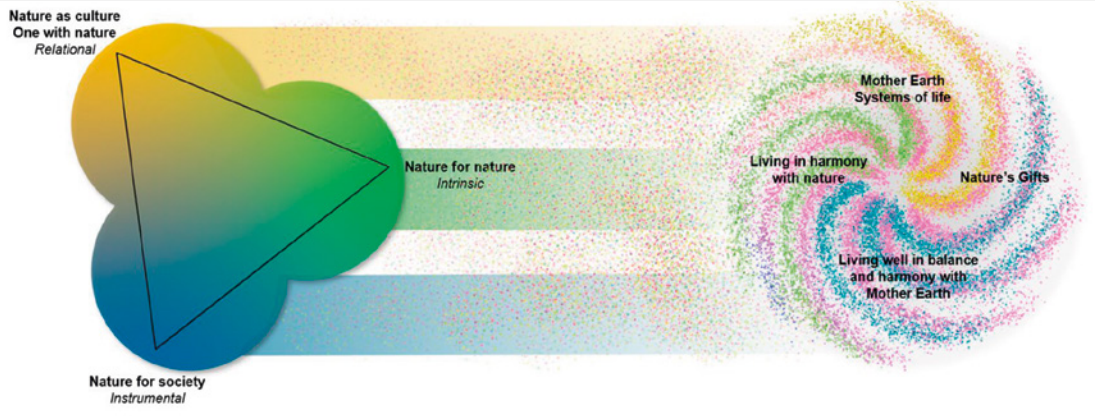


Figure 3 3 **The Nature Futures Framework.**

A flexible tool to support the development of scenarios and models of desirable futures for people, nature and Mother Earth, and its methodological guidance. Source: IPBES (2023b).

The NFF has been applied in diverse ways through research communities around the globe (IPBES, 2023b). For example, new visions were developed by youth in Latin America, for the conservation of high seas, and for a new national park in the Netherlands (Kingdom of the) by exploring and incorporating diverse values of nature in envisioning the future (Kuiper *et al.*, 2022; Pereira *et al.*, 2023; Rana *et al.*, 2020). In Hindu Kush Himalaya, Dasgupta & Shakya (2023) developed an analytical framework in which the NFF is used to develop ecosystem services-oriented pathways for sustainable futures. In Nepal, the NFF informed on how access to information about climate impact, legal barriers and reinforcement from the authority can potentially redirect forest management professionals to consider multiple benefits of nature in management processes (Karki, 2022).

Stronge *et al.* (2023) used the framework with Māori people in New Zealand to develop shared goals for maintaining soil health and well-being and found multiple co-existing values, confirming that the inclusivity of value perspectives within the framework allowed the cultural perspectives of Māori people to be captured. Sarkar *et al.* (2020) developed “Rights for Life” scenarios for achieving biodiversity targets and social equity for IPLC and found that explicitly recognising the rights of people can build a basis for new regulations, policies and governance. Using the Half Earth and Sharing the Planet scenarios and the NFF value perspectives, De Bruin *et al.* (2023) found that perceptions on equity are linked to how people perceive nature, their professional focus and their view on conservation and development today, thus demonstrating how incorporating different equity issues in scenarios can lead to more inclusive policy design.

In New Zealand, Diprose *et al.* (2022) used the NFF value perspectives to categorize the self-reported outcome of the New Zealand Garden Bird Survey and subsequent impact/actions for people and nature. The study found that the NFF lens helps create space for relational aspects between people and nature as well as between people. Palacios-Abrantes *et al.* (2022) explored how the NFF can identify trade-offs between alternative climate change adaptation pathways focusing on different nature values and concludes that diverse perspectives of people’s values could lead to adaptive decision-making and policy that is resilient to climate change. For a transformation in the economic system, Otero *et al.* (2022) proposes methodological approaches for developing degrowth scenarios for biodiversity using the NFF and calls for a community of practice to realize the effort.

While diverse in its application across realms and regions, the NFF has not been used widely in exploring nexus issues and how new visions can help achieve policy coherence between biodiversity and other sectors. However, there are currently ongoing efforts in this area visioning nature-people positive futures using the NFF in Europe, focusing on the nexus among biodiversity, water, food, health, climate change, energy and transport (BIONEXT, 2023).

One of the objectives of the NFF (Pereira *et al.*, 2020) is to support the generation of global- and regional-scale scenarios that engage with ILK or that are developed with IPLC participation, by focussing on values, particularly relational ones (e.g., nature as culture/one with nature). Through the dialogue workshops organized by the Indigenous and local knowledge (ILK) technical support unit of IPBES, an exchange with IPLC was organized to provide feedback on the framework and develop visions and pathways for regional scenarios (IPBES, 2022). In the previous dialogues, the focus on value systems resonated with participants, with some welcoming the inclusion of nature as culture/one with nature, and many relating the different values to characteristics of relationships between IPLC and other actors. It was suggested that a

Box 3 2

cyclical shape of the NFF framework would better represent the holistic interconnectedness of fundamental elements in IPLC cosmologies (often nature, universe and people) while a triangle might be perceived as implying a hierarchy within values. Participants also reflected on how they explore the future and relate to scenarios as a way to do so: some recognized the value of looking into the future with good and bad scenarios and ways to strike a balance between objectives, while others recognized the value of IPLC not only envisioning their future but also reviewing and contributing to the production of scientific knowledge *via* co-production approaches. Decolonization, moving away from western values of profit from nature to more relational values between nature and people, and the recognition of IPLC as key actors and stewards of nature were proposed as key features of the way forward. However, co-design processes must be tailored to specificities reported by participants on how IPLC engage with the future: for example, projections into the future are rooted in understanding of the present and the past which need to be an integral part of the scenario design process; the future is not necessarily viewed as an endpoint but through the lens of stability in the system, considering issues of rights recognition and cultural transmission.

3.1.3 Chapter organization

The chapter is structured into five main **sections** (**3.2** to **3.6**; **Table 3.1**) that synthesize evidence from scenarios that emerge from each of the nexus elements, i.e., biodiversity, water, food, health and climate change-oriented scenarios. For each of these sections, the key drivers that influence the nexus element and its interactions with other nexus elements is first discussed. Then each section is broken down into specific types of scenario studies, for example, for biodiversity-oriented scenarios this covers scenarios that focus on biodiversity policy targets, nature conservation, and ecosystem degradation and restoration, while for water this covers scenarios that focus on water quality, water demand and water supply. For each scenario type, impacts, feedbacks, synergies and trade-offs among the nexus elements are discussed in relation to response options (measures or actions) and indirect and direct drivers for terrestrial, freshwater and marine realms. A synthesis across all scenario studies is provided in **section 3.7** with respect to drivers, nexus interactions, global policy targets, decision support tools for nexus decision-making, implications for IPLC, and uncertainties and knowledge gaps.

Table 3 1 **List of the specific types of scenario studies covered under the different nexus elements, which comprise the chapter sections and sub-sections.**

Chapter section	Specific types of scenario studies	Description of scenario
Biodiversity	Biodiversity targets	These scenarios focus on achieving specific biodiversity targets such as halting the decline of species populations
	Nature conservation	These scenarios focus on achieving area-based or action-based conservation targets such as the 30 by 30 target
	Ecological degradation and restoration	These scenarios focus on reducing degradation of ecosystems or alternative pathways to their restoration
Water	Water quality scenarios	Scenarios focused on water quality improvement or decline
	Water demand scenarios	Scenarios of allocation of water among sectors to meet future needs
	Water supply scenarios	Scenarios of water quantity management such as dam construction and flood mitigation
Food	Food demand scenarios	Scenarios focused on the increasing demand for food, mostly driven by population, incomes and preferences
	Food supply scenarios	Scenarios focused on the production side of the food system
	Integrated food scenarios	Scenarios focusing on both the supply and demand sides of the food system

Table 3 1

Chapter section	Specific types of scenario studies	Description of scenario
Health	Infectious diseases, vector-borne diseases and zoonoses for health	Scenarios focusing on transmittable diseases, for example, those transmitted through human-wildlife contact
	Green and blue spaces	Scenarios focused on the role of nature on physical and mental health
Climate	Climate change impacts	Scenarios exploring future impacts of climate change across the nexus
	Climate change mitigation	Scenarios exploring nature-based solutions to climate change mitigation across the nexus
	Climate change adaptation	Scenarios that explore alternative options for adapting to future climates across the nexus

3.2 BIODIVERSITY-ORIENTED SCENARIOS AND THEIR NEXUS INTERACTIONS

This section synthesizes the scenario literature on biodiversity and its interactions with the other nexus elements of water, food, health and climate change. It is structured according to three types of biodiversity scenarios: (1) scenarios of biodiversity policy targets; (2) scenarios of nature conservation; and (3) scenarios of degradation and restoration.

Several scenarios have been developed that describe future impacts of drivers on biodiversity and future implications for biodiversity policy goals, nature conservation, ecosystem degradation and conservation strategies. All 186 nexus scenarios assessed in this chapter considered biodiversity, since this was a prerequisite for a scenario to be included in the analysis. Of the 186 systematically assessed nexus scenarios, 15 included an assessment of biodiversity policy targets, 52 of nature conservation, and 12 for degradation and restoration. Most of the studies were at the global scale, and only 3 studies included ILK.

3.2.1 Impacts of multiple drivers on biodiversity and nature's contributions to people (NCP)

Most of the assessed scenarios explore the impacts of multiple drivers on biodiversity and NCP. Drivers include land-, freshwater- and sea-use change, habitat loss, overexploitation of natural resources including the direct harvesting of plants and animals, climate change, pollution, infrastructure development and the spread of invasive alien species. All these drivers act across spatial and temporal scales, as well as across terrestrial, freshwater and marine realms. Scenarios typically focus on the strongest drivers of terrestrial biodiversity loss: land-use or climate change (P. A. Harrison *et al.*, 2019; Kok *et al.*, 2018, 2023; Leclère *et al.*, 2020; Veerkamp *et al.*, 2020; Visconti *et al.*, 2016; WWF, 2020b). There is consensus amongst scenarios that both biodiversity and all other nexus elements are at risk from multiple drivers, with implications for the environment, people and economies at different scales.

Evidence from BAU scenarios (Kok *et al.*, 2018; P. W. Leadley *et al.*, 2014; Tallis *et al.*, 2018) suggest that climate change affects the productivity and resilience of ecosystems, with projections showing a growing challenge to ecosystem integrity and functioning by 2050. Climate change will affect genetic, species and ecosystem levels, including shifts in the distribution of species and ecosystems, changes in species abundance and increased risk of extinctions, with projected changes and their drivers varying substantially geographically (IPCC, 2022a; P. W. Leadley *et al.*, 2014). Biodiversity-rich regions such as sub-Saharan Africa, South Asia, Southeast Asia, the Caribbean and Latin America are probably most at risk.

Biodiversity will also be impacted strongly by indirect drivers such as demographic, socio-economic and technological changes, including lifestyle changes. The complex interactions between social, economic, political and biophysical systems highlight the challenge of developing sustainable pathways for development and nature conservation. The evidence from scenarios is unequivocal in demonstrating that there is no "one solution fits all" approach to achieving sustainable biodiversity targets (P. Leadley *et al.*, 2022). Reversing biodiversity loss requires a nexus approach that simultaneously examines interactions among multiple sectors along with synergies and trade-offs among goals. For example, Leadley *et al.* (2022) show that no single target acting on direct drivers of biodiversity loss contributes more than 10-15 per cent to the achievement of any one biodiversity outcome of the Kunming-Montreal Global Biodiversity Framework.

Reducing or minimizing the direct and indirect drivers on biodiversity and NCP, however, will require substantial departures from BAU pathways. Existing target-seeking scenarios illustrate how biodiversity will continue to decline if society continues its current path – unevenly so among different regions – unless rapid and integrated action is taken to reduce the direct drivers of ecosystem destruction. This calls for the implementation of different interventions and conservation strategies that will have future consequences and trade-offs for other nexus elements, such as food security, resource extraction and clean energy provisioning (Leclère *et al.*, 2018; Mace *et al.*, 2018; Oberdorff, 2022) (see also **Chapter 5.1, section 5.1.3**).

3.2.2 Scenarios focused on biodiversity targets

Fifteen biodiversity target-seeking scenario studies explore how to move from today to futures that reverse biodiversity loss and meet policy targets, such as the Kunming-Montreal Global Biodiversity Framework. These scenarios project biodiversity and NCP trends and their implications for the nexus to 2050 and beyond. Some studies were based on the Aichi biodiversity targets for 2020 and the vision for 2050 to "bend the biodiversity curve" (Kok *et al.*, 2018, 2023; Leclère *et al.*, 2018, 2020; Visconti *et al.*, 2016) **(Box 3.3)**. In addition, some scenarios focus on the SDGs that limit net loss of natural habitat by halting deforestation (Tallis *et al.*, 2018). Target-seeking studies are biased towards the terrestrial realm, with no scenarios for the marine realm alone and only one study, Kok *et al.* (2023), that evaluated the terrestrial and freshwater realms together. Additionally, although important (Díaz *et al.*, 2019; Kozicka *et al.*, 2023), none of the scenarios were developed with stakeholder involvement and consideration of ILK.

Despite the negative outcomes found in future scenarios and the challenges of multiple drivers acting on biodiversity, evidence from target-seeking scenarios and pathways (Kok *et al.*, 2018; Leclère *et al.*, 2018; Tallis *et al.*, 2018; Visconti *et al.*, 2016) indicate that a world that achieves many of the global biodiversity targets and sustainability goals is not beyond reach. Future biodiversity losses can be avoided and the biodiversity trends from habitat conversion can be reversed by 2050. For example, in the sustainability scenario of Tallis *et al.* (2018) over 50 per cent of each of the 14 global biomes remain as natural habitat, except for temperate grasslands. However, substantial changes from BAU trends are needed to meet the objective of slowing and then stopping the loss of terrestrial biodiversity. It is also clear that no single action can achieve all biodiversity targets. When and how biodiversity loss is halted and reversed will depend on the timing and type of actions. Additionally, positive outcomes vary by biodiversity indicator type, spatial and temporal scale, and contexts. The "option space" to implement the necessary measures also differs between world regions because of differing priorities, contexts and synergies and trade-offs.

Bending the curve (Leclère *et al.*, 2020) and sustainability (Tallis *et al.*, 2018) scenarios demonstrate that long-term biodiversity goals can only be met by combining a broad and ambitious portfolio of measures. These measures include mitigating climate change, behavioural change, enhancing biodiversity protection, sustainably managing fisheries and targeting other drivers of habitat conversion through land-use changes that include rapid shifts to more equitable and sustainable agricultural production approaches, particularly in areas with higher yields and lower water stress. However, the capacity to produce food

Box 3 3 **Bending the curve of biodiversity loss.**

The concept of "bending the curve" of biodiversity loss refers to strategies and actions aimed at halting and ultimately reversing biodiversity decline (Mace *et al.*, 2018), as aligned with the 2050 Vision from the Convention on Biological Diversity (Living in Harmony with Nature). One of the seminal papers that framed the conversation was "Aiming higher to bend the curve of biodiversity loss" by Mace *et al.* (2018), which argued for the necessity of transformative changes across economic, social, political and technological dimensions to achieve tangible conservation outcomes.

Building on an extensive science-policy assessment process, the IPBES Global Assessment Report on Biodiversity and Ecosystem Services (IPBES, 2019) concluded that "bending the curve" requires tackling the root causes of biodiversity loss: the interconnected economic, sociocultural, demographic, political, institutional and technological indirect drivers behind the direct drivers of biodiversity loss. Such transformation will require innovative governance approaches that are adaptive, inclusive, informed by existing and new evidence and integrative across systems, scales of biodiversity, jurisdictions and tools (Díaz *et al.*, 2019).

To effectively "bend the curve," interdisciplinary and integrated approaches are essential, including sustainably increased crop yields and trade in agricultural goods, reduced food waste, dietary shifts, increased extent and management of protected areas and increased restoration and landscape-level

Box 3 3

conservation planning (Leclère *et al.*, 2020). Leclère *et al.* (2020) utilized an ensemble of scenarios and modelling techniques to project the outcomes of various conservation strategies on global biodiversity trends.

The results indicate that increased conservation alone will not be sufficient, but that combining this with additional sustainable production and consumption measures could potentially reverse the declining trends in biodiversity before 2050 **(Figure 3.4)**. The results also indicate that siloed strategies might entail trade-offs with some of the sustainable agenda goals (e.g., food security risks associated with ambitious conservation efforts) while combined strategies would limit those trade-offs and instead entail co-benefits across goals (e.g., climate change mitigation and health benefits).

By providing a quantitative analysis of the trajectories of biodiversity decline under different conservation scenarios, the study offered a roadmap for policymakers, conservationists and stakeholders on how to successfully bend the biodiversity curve. Furthermore, it illustrated what integrated action might entail to inform qualitative and quantitative aspects of the Kunming-Montreal Global Biodiversity Framework. Beyond models and scenarios (P. Leadley *et al.*, 2022), the concept has also been used in multiple other research and policy contexts (Britton *et al.*, 2023; Tickner *et al.*, 2020; WWF, 2020a). For instance, Tickner *et al.* (2020) reviewed evidence on what bending the curve means for freshwater biodiversity, what interventions will be required and how major policy frameworks could be adjusted to better support this goal, while follow-up studies proposed specific components of integrated strategies to address multiple threats to freshwater biodiversity (Arthington *et al.*, 2023).

Importantly, these efforts require close collaboration between different types of societal actors, including, among others, governments at international and national levels, business and finance sectors, researchers, the conservation community and civil society, and IPLC (Mace *et al.*, 2018). Addressing equity and justice issues associated with transformative change, as well as exploring alternative value perspectives about human-nature relationships, are likely key enabling factors (Obura *et al.*, 2023; Pascual *et al.*, 2023).

To assess the effectiveness of efforts to bend the curve, clear and measurable indicators are needed (Jetz *et al.*, 2019). These indicators should be aligned with global targets and consider ecological, economic and social dimensions of biodiversity (Soto-Navarro *et al.*, 2021).

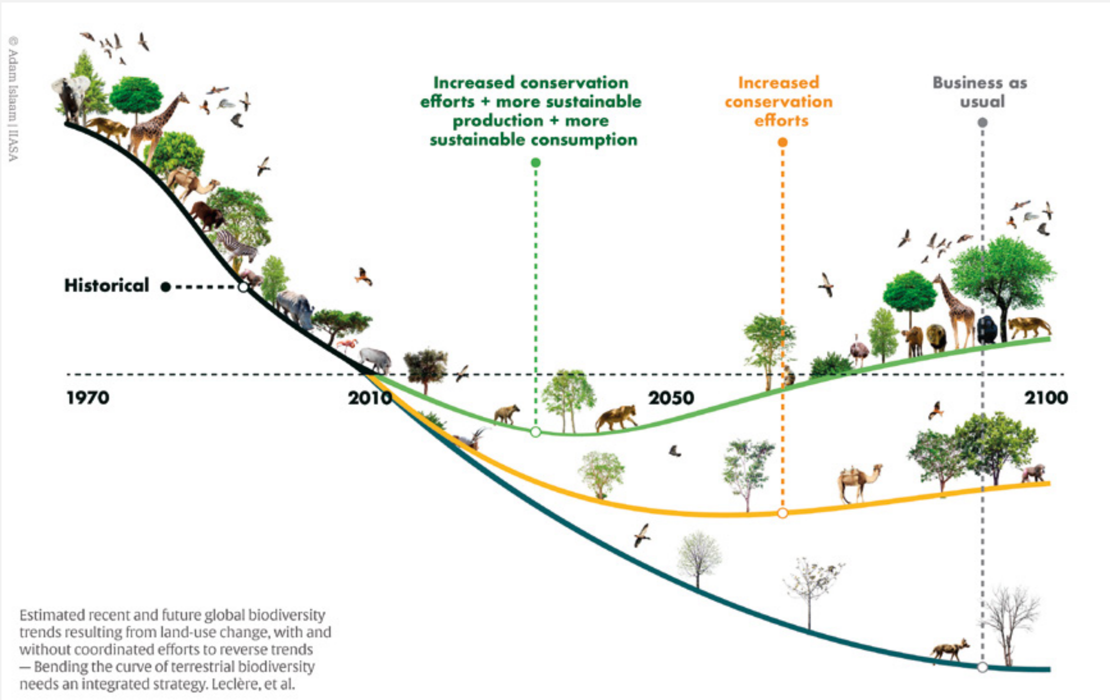


Figure 3 4 **Bending the curve.**

Adapted from Leclère *et al.* (2020). Bending the curve of terrestrial biodiversity needs an integrated strategy. The figure illustrates the main findings of the article but does not intend to accurately represent its results.

sustainably is context specific. Furthermore, transforming energy production from primarily fossil fuels to renewable sources and more broadly decarbonizing the energy system would benefit biodiversity and food security. Consumption measures are also needed, for example reducing food waste and increasing sustainable healthy diets with a focus on plant-based proteins (where possible and appropriate). Prioritizing sustainability pathways not only achieves the 2050 Vision from the Convention on Biological Diversity of Living in Harmony with Nature but will lead to other positive outcomes such as reducing greenhouse gas emissions to limit global warming to 2°C by 2100; eradicating hunger by 2050; and providing universal access to safe drinking water, improved sanitation and modern energy.

3.2.3 Scenarios focused on nature conservation

Management for nature conservation through protected areas and other effective area-based conservation measures (OECMs) is used in scenarios to facilitate positive biodiversity outcomes by averting further declines and influencing other nexus elements. Nature conservation refers to a site-based legal, tenure or governance system with the primary goal of preserving biodiversity, its processes or NCP, and supporting the sustainable use of nature. The specific form of nature conservation to be established, by whom and when is dependent on local contexts and appropriateness of management (Arneth *et al.*, 2023; Barnes *et al.*, 2018; Visconti *et al.*, 2019). Scenarios for nature conservation are usually constructed by assessing either the potential opportunities, synergies and trade-offs that might arise from implementing nature conservation measures in an area or by simulating nature conservation actions as land- or water-use practices that displace or affect other nexus elements. A total of 52 studies (22 terrestrial, 17 marine and 13 freshwater) were found to have investigated nature conservation scenarios.

3.2.3.1 Terrestrial realm

Terrestrial nature conservation actions provide a range of synergistic benefits for other nexus elements and NCP (i.e., Stolton *et al.*, 2015). However, trade-offs, such as the displacement of land- or water-use activities, can potentially increase pressures on other nexus elements such as food or health (Henry *et al.*, 2022; Leclère *et al.*, 2020; Staccione *et al.*, 2023). For example, Staccione *et al.* (2023) found that under a SSP1-2.6 or SSP3-4.5 pathway the establishment of new European strictly managed protected areas would likely lead to an intensification of food production outside protected areas. Hence, establishing nature conservation in isolation and without consideration of other nexus elements might jeopardise biodiversity in other areas (Jung *et al.*, 2021; Leclère *et al.*, 2020) and sustainable development or climate goals (Arneth *et al.*, 2020, 2023). A range of studies found that to maximize synergies and reduce trade-offs with other nexus elements, planning processes for conservation actions should integrate different perspectives, sectoral targets and ambitions (Jung *et al.*, 2021; Kok *et al.*, 2018, 2023; Leclère *et al.*, 2020). Integrated planning for future conservation actions considers not one but multiple objectives, for example, by specifying concrete targets for nature conservation as well as food production or climate change mitigation (Chapman *et al.*, 2023; Fastré *et al.*, 2021; Jung *et al.*, 2021; Lanzas *et al.*, 2019).

Integrated planning scenarios show that expansion priorities for nature conservation can be synergistic with climate change mitigation objectives (Chapman *et al.*, 2023; Hannah, Roehrdanz, Marquet, *et al.*, 2020; Jung *et al.*, 2021), preservation of water stocks (F. Frank *et al.*, 2023; Jung *et al.*, 2021) and sustainable food production (Chapman *et al.*, 2023; F. Frank *et al.*, 2023; Law *et al.*, 2021). For example, in the Argentinian dry Chaco, the greatest synergies for biodiversity, climate change mitigation and food production could be generated in multi-functional and mixed managed landscapes (Law *et al.*, 2021), with the option space of implementing such plans shrinking as biodiversity loss continues. Proactive conservation actions taken earlier rather than later may be able to reduce future trade-offs between nature conservation and food security, while supporting sustainable healthy diets and the bioeconomy (Leclère *et al.*, 2020; Verniest *et al.*, 2022; Williams *et al.*, 2021).

Several scenarios suggest that expanding nature conservation areas alone will be insufficient to reach ambitious biodiversity policy targets (Kok *et al.*, 2018, 2023; Leclère *et al.*, 2020). Expansion of strict nature conservation areas by 30 per cent or more could lead to trade-offs and negative impacts on healthy diets due to increases in food prices, disproportionately so in less developed countries (Henry *et al.*, 2022; Kok *et al.*, 2023; Staccione *et al.*, 2023), or negatively impact the production of rainfed bioenergy crops for climate change mitigation (W. Wu *et al.*, 2019). Ambitious transformative changes in the food system could mitigate such trade-offs in areas where nature conservation is established (Kok *et al.*, 2018; Machovina *et al.*, 2015; W. Wu *et al.*, 2019). There is increasing evidence that only through an integrated perspective that combines actions mitigating impacts of multiple nexus elements (Kok *et al.*, 2023; Leclère *et al.*, 2020), will society be able to deliver effective nature conservation measures.

Integrated planning can integrate horizontally across nexus elements and maximize future synergies (Gerling *et al.*, 2022; Jung *et al.*, 2021; Strassburg *et al.*, 2019). However, different evidence exists across scales to robustly identify synergies and trade-offs (Chaplin-Kramer *et al.*, 2022). In particular, the over reliance of nature conservation scenarios on area-based, rather than efficiency-based, targets might jeopardize the goal of preventing further biodiversity loss (Arneth *et al.*, 2023; Visconti *et al.*, 2019). Less than one third of all assessed studies (~26 per cent) considered targets that were not exclusively area-based. Here, the involvement and collaboration with ILK in achieving nature conservation targets might help to identify those situations where trade-offs are usually ignored or challenging to quantify (Makondo & Thomas, 2018; McElwee *et al.*, 2020). This could contribute to increasing equity and safeguard access and benefit sharing mechanisms (Atsali, 2020), and might determine whether nature conservation measures bring the expected benefits for biodiversity as well as other nexus elements.

3.2.3.2 Freshwater realm

Although freshwater biodiversity is among the most threatened globally (I. J. Harrison *et al.*, 2018), nature conservation scenarios in such ecosystems are rare (Abell *et al.*, 2007; van Rees *et al.*, 2020). Freshwater nature conservation is commonly established through the protection of ecological processes and upstream water sources, OECMs, such as community managed watersheds (Gurney *et al.*, 2021; Wiik *et al.*, 2020), or catchment scale efforts to conserve water sources (Abell *et al.*, 2019; Moravek *et al.*, 2023). Given evidence that European freshwaters might lose almost half of their provisioning and regulating ecosystem services due to changes in climate and water demand (Okruszko *et al.*, 2011), the effective implementation of freshwater protection has been highlighted as a key enabler to bend the curve of freshwater biodiversity loss (Tickner *et al.*, 2020).

Nature conservation in riverine freshwater systems is usually complicated by their inherent dynamics, and direct and indirect drivers affect biodiversity beyond a specific location, often interacting across realms and scales (Abell *et al.*, 2019; Pittock *et al.*, 2015; van Rees *et al.*, 2020). Increasing water demands for agriculture have severely degraded freshwater protected areas in Europe (Navedo *et al.*, 2022), while climatically driven declines in precipitation (Markovic *et al.*, 2017; Okruszko *et al.*, 2011), or freshwater associated diseases will further increase future trade-offs with freshwater conservation (Herrera *et al.*, 2017; Sokolow *et al.*, 2017).

There is good evidence on the interactions between freshwater nature conservation and climate change mitigation and adaptation. For example, hydropower usually prevents environmental flows downstream and affects key ecological processes in freshwater conservation areas (Belletti *et al.*, 2020; van Rees *et al.*, 2020). Evidence suggests substantial benefits in interlinked freshwater planning, with potential dam removal in the Willamette River watershed reconnecting 52 per cent of critical salmon habitat benefiting genetic diversity, while sacrificing less than 2 per cent of renewable energy and provisioning capacity (Kuby *et al.*, 2005). Strategic barrier removal could provide biodiversity benefits while also reducing impacts on renewable capacity, water flows and economic costs (Hermoso *et al.*, 2012, 2018; Intralawan *et al.*, 2018), and in some examples from tropical rivers reduce the risk of over 400 million people affected by schistosomiasis (Sokolow *et al.*, 2017).

Consideration of terrestrial drivers of freshwater biodiversity loss and trade-offs with terrestrial conservation actions would benefit freshwater conservation actions (I. J. Harrison *et al.*, 2016; Pittock *et al.*, 2015). For example, afforestation in the upper catchment of freshwater catchments can reduce river flows downstream owing to the increase in evapotranspiration and reduction in environmental flows (Pittock *et al.*, 2015). Furthermore, unsustainable forms of food production in catchment areas and pollution from urban areas are projected to affect conservation outcomes, water supply and quality in rivers and lakes downstream (Ba *et al.*, 2020; Lemaire *et al.*, 2022; A. J. Wade *et al.*, 2022). Increases in wetland water levels have been found to bring co-benefits for biodiversity, climate regulation and water provisioning (Fisher *et al.*, 2011). However, evidence on future synergies between freshwater conservation and food provisioning is inconclusive, despite most freshwater ecosystems being a major food source in areas with few options for farming (McIntyre *et al.*, 2016). Overall, evidence suggests that to be effective, planning for freshwater conservation would benefit from being integrated by explicitly considering factors acting at catchment scale, across realms as well as other nexus elements (Adams *et al.*, 2014; Giakoumi *et al.*, 2019; Leal *et al.*, 2020; Moravek *et al.*, 2023; van Rees *et al.*, 2020).

3.2.3.3 Marine realm

The main tools for ocean conservation are marine protected areas (MPAs) and OECMs (Petza *et al.*, 2023), which together currently equal 8.2 per cent of the global ocean area (UNEP-WCMC & IUCN, 2023a, 2023b). Only a very small component (1 per cent) are OECMs and only 2.9 per cent are fully or strictly protected MPAs. Given the smaller proportion of the area of ocean in Exclusive Economic Zones (EEZs) and the number of activities already occurring there compared to the Areas Beyond National Jurisdiction (ABNJ), it is unlikely that the 30 per cent target of target 3 of the Kunming-Montreal Global Biodiversity Framework will be met without establishing protection in the High Seas. Thus, the 2023 agreement under the United Nations Convention on Law of the Sea on the conservation and sustainable use of marine biodiversity beyond national jurisdiction is a welcome addition to potential solutions.

To ensure effective conservation, multi-objective planning is necessary that maximizes protection and restoration of ecosystems along with sustainable use of resources, while mitigating drivers of biodiversity degradation, such as climate change and habitat loss. Prioritizing objectives independently when substantially increasing the current coverage of MPAs can lead to large trade-offs between biodiversity, carbon stocks and fisheries catch, while multi-objective planning could triple potential benefits by increasing biodiversity, increasing fisheries capture and minimizing carbon stock loss (by reducing trawling) globally (Sala *et al.*, 2021) and regionally (B. Bauer *et al.*, 2019; Bryndum-Buchholz *et al.*, 2023; Gomei *et al.*, 2021). Increasing protection in some areas while sustainably managing activities elsewhere can lead to increased commercial fish stocks under moderate climate change scenarios (Gomei *et al.*, 2021). Spatial planning in the high seas could help to meet conservation targets across climate scenarios if the cost of fishing remained low. However, the areas selected for conservation varied among scenarios and cost of fishing (Brito-Morales *et al.*, 2022). The combination of different depths and climate scenarios supports the implementation of a climate smart network of MPAs that minimises exposure to climate change, conserves biodiversity and retains species (Brito-Morales *et al.*, 2022). Unfortunately, predicted locations of Vulnerable Marine Ecosystems (such as deep-water corals and sponges) under future climate change scenarios (based on Morato *et al.*, 2020), were not well represented (< 6 per cent) in a study that examined optimization of conservation targets, area-based costs, opportunity costs to bottom-fishing activities and potential deep-sea mining activities and current conservation measures (Combes *et al.*, 2021).

Pro-active ocean planning to meet targets for multiple objectives under future climate scenarios compared to interventions based on present day conditions does not always incur significant trade-offs. For example, (Pinsky *et al.*, 2020) assessed trade-offs using more than 11,000 projections of future species habitat distributions (2041-2060 and 2081-2100) for 736 species across eight climate models for scenarios RCP2.6 and RCP 8.5. The study showed that planning that integrates future redistributions of species met a much higher percentage of the goals by mid-century than in the absence of such integration with little or no trade-off in area needed.

However, climate change risks for marine biodiversity depends on species and ecosystem traits. Understanding these risks is crucial in designing effective nature conservation strategies. For example, a global climate risk index applied to approximately 25,000 species under different climate scenarios showed that 90 per cent of species evaluated are at high or critical risk under the extreme warming SSP5-8.5 scenario, particularly for commercial species in low-income countries that highly depend on fisheries (Boyce *et al.*, 2022). A mitigation strategy (represented by SSP1-2.6) would reduce the risk for all species, enhance ecosystem stability and benefit low-income countries the most.

Guidelines on how to prepare MPAs for climate change are also emerging at the regional level. For example, in Canada steps are being taken to design a climate-smart marine conservation network that contributes to both the protection of biodiversity and climate change mitigation (Bryndum-Buchholz *et al.*, 2022). This aims to ensure that under the high emissions scenario that no existing MPA and OECM in Atlantic Canada will overlap with any identified climate refugia, while 75 per cent of MPAs and 39 per cent of OECMs will be within climate change hotspots (Bryndum-Buchholz *et al.*, 2023).

3.2.4 Scenarios focused on ecosystem degradation and restoration

Land degradation continues to be an enormous challenge to human societies (Arneth *et al.*, 2021; Costa *et al.*, 2020; IPBES, 2018a; Manici *et al.*, 2014). Globally, the environmental degradation affecting terrestrial food systems could increase by 50 to 90 per cent between 2010 and 2050. Degradation of estuaries and coastal seas has been occurring for centuries, with more than 90 per cent decreases in the abundance of ecologically important species, more than 65 per cent loss of wetlands and accelerated species invasion (Lotze *et al.*, 2006). Restoration efforts to reverse this degradation have proven to be both expensive and difficult to scale-up (Bayraktarov *et al.*, 2016; Fraschetti *et al.*, 2021).

Ecological restoration is "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (Gann *et al.*, 2019). The Kunming-Montreal Global Biodiversity Framework target 2 requires at least 30 per cent of the total cumulative area of degraded terrestrial, inland water and marine and coastal ecosystems to be under effective restoration by 2030. Achieving this target will require careful planning to minimize trade-offs with food production and energy provision, although there might be synergies with biodiversity and water objectives.

Restoration action is becoming more evident through initiatives such as the UN Decade on Restoration (2021 to 2030), dedicated to promoting and recognizing international efforts in restoration including 10 groundbreaking ecosystem restoration initiatives worldwide. These flagship initiatives aim to restore more than 68 million hectares in 23 countries (UNEP, 2023) within varying timeframes. Furthermore, some countries have promised massive restoration efforts, such as Brazil which claims that 12 million hectares will be restored by 2030 (Borma *et al.*, 2022). Restoration projects can bring benefits to other nexus elements, such as climate regulation, provision of clean water, erosion control and flood mitigation (Borma *et al.*, 2022). Some global scenarios show that restoring 15 per cent of converted land in priority areas could prevent 60 per cent of expected extinctions while potentially sequestering 300 Gt of carbon (Strassburg *et al.*, 2020). Other studies also find synergies with improved water storage (Taffarello *et al.*, 2017) and better conditions for agriculture (e.g., K. Liu *et al.*, 2023).

However, interlinkages between vegetation dynamics and water availability vary by region (Borma *et al.*, 2022; K. Liu *et al.*, 2023; Silva *et al.*, 2023). In regions with low water supply yet high demand, such as the Aral Sea, scenarios of restoration efforts for the 2021-2050 period show trade-offs with food supply as there is a need to regulate and decrease cropland (Ma *et al.*, 2023) to promote restoration efforts. This reduction in food production affects local livelihoods culminating in conflict. Similarly, future hydrological variability in response to vegetation dynamics is a critical issue for regional water resource and climate management (K. Liu *et al.*, 2023), although evidence from restoration scenarios from a nexus perspective are lacking with which to design approaches that promote synergies with water, food, health and climate change.

3.2.4.1 Terrestrial realm

Restoration is relevant across a wide range of terrestrial ecosystems, but more emphasis has been placed on scenarios of reforestation/afforestation (e.g., Costa *et al.*, 2020b). However, reforestation/afforestation are not necessarily the same as restoration if, for example, monocultures are planted instead of species that respect local ecological integrity (Arneth *et al.*, 2021; Jung, Lesiv, *et al.*, 2023). In general, reforestation/afforestation and other conservation measures, or natural climate solutions, can provide up to 37 per cent of the cost-effective CO_2 mitigation up to 2030, with positive impacts on other nexus elements such as water, soil and biodiversity (Griscom *et al.*, 2017) with half of this mitigation due to carbon sequestration in restored forests by 2030. In the US, for example, natural climate solutions and avoided conversion potential are equivalent to 21 per cent of current annual emissions, with co-benefits such as air and water filtration, flood control, soil health, wildlife habitat and climate resilience (Fargione *et al.*, 2018).

Scenarios that focus on the achievement of reforestation/afforestation targets such as the Bonn Challenge or climate change mitigation targets have been shown to require transformation in the food system (such as technological transitions and dietary shifts) to make more land available for tree planting (Lee *et al.*, 2019). Reforestation/afforestation scenarios also show conflicting land-use interests for agriculture and cattle ranching (Costa *et al.*, 2020). Furthermore, reforestation/afforestation at one location can have indirect land-use change effects on other parts of the world through the displacement of food production (Staccione *et al.*, 2023) or impacts on the water cycle (Krause *et al.*, 2019).

There are very few examples of large-scale scenarios of restoring degraded land; one study aimed to achieve the goals of the 2030 Agenda for Sustainable Development and the Kunming-Montreal Global Biodiversity Framework (Arneth *et al.*, 2021), and found that meeting these targets would require an increase in global tree cover of 4 million km² that would increase forest carbon stocks by 50 Gt and protect 28 per cent of the terrestrial surface with high biodiversity and carbon values. However, increasing forest areas also led to the contraction and further intensification of cropland and pastureland, in some scenarios causing negative impacts on many carbon and biodiversity hotspots in the Americas, India and Indonesia due to land-use displacement (Arneth *et al.*, 2021; Simkin *et al.*, 2022).

Other sources have shown that biodiversity and climate change objectives can be achieved jointly and cost-effectively through spatially integrated, ecosystem restoration (Strassburg *et al.*, 2020). However, restoration aimed at delivering multiple benefits poses challenges and trade-offs which are constrained by limited funding and competition with other land-uses, particularly food production (Budiharta *et al.*, 2016, 2018). Although restoring biodiversity may be costly with uncertain results in the long run, the cost of inaction (leaving degraded land unrestored) is much higher. For example, in Africa, it was found that action in 42 studied countries would provide a surplus of $2.83 trillion over the next 15 years through soil nutrient conservation from avoided erosion. Conserving intact nature in the first place is also more cost-effective than restoring it after degradation (Budiharta *et al.*, 2018; Curran *et al.*, 2014; Gibson *et al.*, 2014).

3.2.4.2 Freshwater realm

Evidence suggests that increased restoration in wetlands can contribute to climate goals (Mu *et al.*, 2022; Perosa *et al.*, 2021) as well as a range of other nexus elements such as food and clean water (Odgaard *et al.*, 2017). For example, Tomscha *et al.* (2021) conducted a study in New Zealand to identify ecosystem services enhanced by wetlands restoration, which demonstrated improved water quality and plant species diversity, but also mitigated climate change impacts through carbon storage and storm water retention. Doelman *et al.* (2023) also used scenarios to demonstrate how peatland restoration could also contribute to climate change mitigation by enhancing carbon stocks. Furthermore, restoration of riverine or coastal areas could contribute to enhanced conservation efforts as well as climate change adaptation by reducing flood impacts (Grossmann & Dietrich, 2012; Menéndez *et al.*, 2020; Odgaard *et al.*, 2017; Perosa *et al.*, 2021).

3.2.4.3 Marine realm

Once commonly considered too costly or prone to failure (Bayraktarov *et al.*, 2016), Marine Ecological Restoration (MER) is now seen as a primary action to recover lost or degraded coastal and marine ecosystems (Duarte *et al.*, 2020; Saunders *et al.*, 2020). This is in response to evidence that MPAs and mitigation of stressors alone cannot rebuild marine life to the extent that is required to achieve societal goals, including supporting biodiversity, climate change mitigation and adaptation, and ecosystem functions and services. Accordingly, more interventionist approaches are being called for (Waltham *et al.*, 2020). Moving forward, an approach which is inclusive of diverse disciplines, sectors and stakeholders is required for MER to be successful in its outcomes (Silliman *et al.*, 2023).

'Blue carbon' is a term coined to represent the relatively high sequestration and storage of carbon in vegetated coastal ecosystems such as mangroves, saltmarshes and seagrasses (Mcleod *et al.*, 2011). Models using spatial data for the area of habitat available for blue carbon ecosystem restoration combined with empirical data for soil carbon content enable estimates of the carbon sequestration benefits of restoration (Hagger *et al.*, 2022; Lovelock *et al.*, 2023). At the global scale, blue carbon ecosystem restoration has the potential to draw down between 0.05-0.8 GtC per year (Griscom *et al.*, 2017; Macreadie *et al.*, 2021; Reynard *et al.*, n.d.), although 0.2 GtC per year is thought to be the theoretical maximum (IPCC, 2022a). Blue carbon ecosystem restoration provides co-benefits, such as supporting commercial fisheries, providing flood control, water filtration, coastal protection, water quality regulation and capture of airborne and waterborne particles and pollutants (Mcleod *et al.*, 2011). Provision of co-benefits along with payments for ecosystem services from blue carbon restoration can benefit people through food provisioning, hazard protection, livelihoods, investment in infrastructure such as school and hospitals, and enhanced emotional well-being (Saunders *et al.*, 2020).

Prioritization of sites for restoration is needed to achieve maximum benefits while minimizing costs by estimating the trade-offs that occur when considering multiple objectives (Adame *et al.*, 2015; Lester *et al.*, 2020; Silliman *et al.*, 2023). At a regional scale, the trade-offs and co-benefits of mangrove restoration have been explored using systematic conservation planning approaches. Prioritizing restoration sites for carbon also yields co-benefits, for example, for biodiversity, fisheries, coastal protection or nitrogen removal. A study of mangroves in the Mexican Caribbean found that selecting cost-effective areas for mangrove restoration for the purpose of carbon sequestration would also ensure that 83 per cent of coastal protection and 75 per cent of water depuration targets would be achieved, respectively (Adame *et al.*, 2015). In catchments in the Wet Tropics of Queensland, Australia, a spatial prioritization approach based on cost-effectiveness analysis was used to examine whether potential carbon credits earned by coastal wetland restoration through tidal reintroduction could incentivize conversion of agricultural land uses to wetland restoration and explored trade-offs in achieving multiple ecosystem services *versus* climate benefit alone (Hagger *et al.*, 2022). Prioritizing site selection for the co-benefits rather than for carbon specifically resulted in 40 per cent less profitability from carbon payments (Hagger *et al.*, 2022).

Climate change impacts, including heat waves and intense storms are causing losses and degradation of coastal habitats (Babcock *et al.*, 2019), with impacts anticipated to worsen in the future, leading to challenges for restoration programmes. Similarly, poor water quality, such as that produced in large flooding events which are driven by catchment clearing and intense rainfall event associated with climate change, causes losses of nearshore habitats including seagrasses, corals and oysters (Saunders *et al.*, 2017). Restoration is a human process, so factors influencing health and food security will influence societal capacity to implement restoration programmes. Accordingly, climate change, population growth and political instability are predicted to reduce capacity to conduct effective ecological restoration (Frietsch *et al.*, 2023).

3.3 WATER-ORIENTED SCENARIOS AND THEIR NEXUS INTERACTIONS

This section synthesizes the scenario literature on water and its interactions with the other nexus elements of biodiversity, food, health and climate change. It focuses on three types of water scenarios: (1) water quality scenarios; (2) water demand scenarios, including future allocations among sectors and management approaches; and (3) water supply scenarios, such as dam building and flood mitigation.

Several scenarios have been developed on potential future impacts of drivers on water, as well as future implications of water-related policy goals, water demand, supply and quality. However, out of those only 35 water-oriented scenarios were found that included an assessment of potential future interactions within the nexus. They include 11 for water quality, nine for demand, and six for supply. Most of the studies were at local to regional scales, and only two studies with water demand entry points included ILK.

3.3.1 Impact of multiple drivers on water

Pressures on freshwater resources are intensifying because of population factors – growth, increased per capita consumption, industrialization, migration to cities and land-use change (Krchnak *et al.*, 2011). Under the BAU scenario, water demand has been estimated to increase by 20-30 per cent in the 2050s compared to the 2010s (Burek *et al.*, 2016), which may further undermine water quality, ecosystem health and biodiversity habitats.

Several assessments have summarized the effects of climate change on different attributes of water resources such as the water budget, biophysical composition, nutrient loading, biodiversity, hydropower generation, frequency of extreme weather conditions, sanitation and hygiene (e.g., Caretta *et al.*, 2022; IPCC, 2021; Meredith *et al.*, 2019). While climate is a driver for water (see **section 3.6**), it is typically not affected by water scenarios, although ecosystem-based scenarios (such as those focusing on hydropower) may provide climate change mitigation benefits.

3.3.2 Scenarios focused on water quality

Scenarios to improve water quality have been considered in many regions. These include reduction of land-based inputs to water bodies, especially from agriculture, and may include restoration activities and nature-based solutions. The available literature suggests that water quality improvement scenarios will benefit both the water and biodiversity nexus elements, and may support climate change mitigation, with mixed results for food and health. The effects of these scenarios will depend on future climate and other drivers.

3.3.1.1 Terrestrial and freshwater realm

Sustainable farming practices and innovative nutrient management are needed to reduce future impacts of agriculture on water quality (Withers *et al.*, 2014). These have been explored using scenarios that include improvements in agricultural practices, which resulted in decreases in nitrogen pollution and increases in water quality (Ducharne *et al.* (2007). Other scenarios have focused on pollution reduction through land-use change by optimizing spatial patterns and decreasing livestock and poultry production (Rong *et al.* (2021), which projected improvements in water quality for drinking water and aquatic ecosystems, but reductions in food production. Water scenario outcomes are also affected by climate change where increased temperatures and lower precipitation has been shown to reduce water flows considerably, making climate change, rather than nutrient usage, the greatest threat to the freshwater ecosystem and biodiversity (Wade *et al.* 2022).

Water quality scenarios that focus on pollutants such as discharging untreated sewage into water courses indicate impacts on the health of aquatic systems, human health and sanitation (Mishra *et al.*, 2017; Kamal *et al.*, 2020; Vermeulen *et al.*, 2015). In some cases, even scenarios assuming a 70 per cent reduction in pollution discharge may not achieve a desirable water quality in the future due to inadequacy of infrastructure (Kamal et al 2020). Under a BAU scenario with current trends in population growth and urbanization, oocyst emissions are expected to increase by a factor 2.0 for India and 2.9 for Bangladesh between 2010 and 2050, which will further deteriorate water quality (Vermeulen *et al.*, 2015).

Water quality scenarios incorporating multiple drivers (climate change, population growth and land-use change) for eight countries in Asia showed that without a robust adaption/mitigation plan which considers direct and indirect drivers, it will be hard to achieve a desirable level of water quality by 2030 (Kumar, 2019). However, water quality improvements can contribute to improvements in biodiversity, human health (through improved drinking water) and food production (through reuse of water) (Boelee *et al.* (2017).

3.3.1.2 Marine realm

In the marine realm, future water quality issues are related to several phenomena. In terms of the linkages between land and sea, coastal erosion, flooding, saltwater intrusion into freshwater sources and rising sea levels are projected to increase the vulnerability of coastal communities (IPCC, 2019). The interplay between land and sea linkages is expected to also affect marine ecosystems, with climate change and land-use change drivers (through increased sediment, nutrients and pollutants) impacting coastal habitats, mangroves, seagrass and coral reefs, resulting in biodiversity loss, habitat modification and loss, and altered ecological dynamics (B. Bauer *et al.*, 2019; Halpern *et al.*, 2008).

Although projections of climate change on marine ecosystems are improving with time (Tittensor *et al.*, 2021), assessing the impact of future scenarios of changes in river runoff on marine ecosystems is challenging due to the high resolution needed in biogeochemical projections to capture accurately the dynamics of coastal environments and phytoplankton dynamics (Gao *et al.*, 2023). Different scenarios using a land-sea model for Fiji showed how land-use (logging and agriculture expansion) and climate change scenarios impact coral reef benthic habitat, including reducing reef fish biomass, with important effects on coral reef resilience and fisheries potential (Delevaux *et al.*, 2018).

Eutrophication associated with excessive nutrient loading is one of the most important anthropogenic pressures impacting marine and coastal ecosystems that is linked to land-use modifying nutrient levels and structures. This includes a selective magnification of nitrogen and phosphorus supply and a reduction of silica (Maúre *et al.*, 2021). These conditions can trigger shifts in phytoplankton composition, formation and persistence of harmful algal blooms (HABs) and hypoxia, with severe symptoms leading to dead zones. Eutrophication can also increase the possibility of jellyfish outbreaks and can contribute to ocean acidification and degradation of shallow water habitats (Maúre *et al.*, 2021).

In Europe, several legislative and management measures have been implemented to halt nutrient overloading and eutrophication in marine ecosystems. Assessment of these nutrient reduction measures by the EU using eutrophication projections to 2030 under a moderate scenario of climate change (RCP4.5) suggests that the measures may not have a significant impact on the structure and function of European marine ecosystems (Piroddi *et al.*, 2021). Among the assessed criteria, the spawning stock biomass of commercially important fish stocks and the biomass of small pelagic fishes would be the most impacted, albeit by less than 2.5 per cent. The impact was lower for species diversity and trophic level indicators. The Black Sea and the North-East Atlantic were the most negatively impacted regions, while the Baltic Sea was the only region that showed signs of improvement. Coastal and shelf areas were found to be more sensitive to environmental changes than large regional and sub-regional ecosystems that also include open seas.

In closed areas such as the Baltic Sea, eutrophication is severely affecting species distributions and ecosystem functioning in coastal areas (Bergström *et al.*, 2013). Scenarios combining fisheries, climate change and nutrient loadings in closed seas like the Baltic highlight the need to address multiple stressors concurrently. For example, under a scenario of low greenhouse gas emissions, low nutrient pollution and ecologically focused fisheries management, outcomes can yield high biodiversity and catch value. On the other hand, scenarios with increasing societal inequality, economic growth based on fossil fuels, high greenhouse gas emissions and high nutrient loads result in decreased habitat quality and diminished biodiversity. Under the latter scenarios, catches are high, but they predominantly consist of lower-valued fish (B. Bauer *et al.*, 2019).

Marine water quality is impaired by harmful algal blooms (HABs), in which rapid and excessive growth of algae that produce toxins can lead to a range of detrimental effects on marine ecosystems, food contamination and human health. HABs disrupt the ecological balance of marine ecosystems by depleting oxygen levels in the water, leading to hypoxic or anoxic conditions that harm fish and other marine organisms (including shellfish, marine mammals and birds), causing mass mortalities that affect food chain dynamics and degrade critical habitats such as coral reefs and seagrass beds (Anderson *et al.*, 2012; Glibert *et al.*, 2014).

Climate change is expected to influence the occurrence and intensity of HABs. Factors such as rising sea temperatures, altered rainfall patterns and changing oceanic currents can create more favourable conditions for the growth and proliferation of harmful algae. These changes can potentially lead to an increase in the frequency, duration and geographic range of HAB events. Excessive nutrient inputs from human activities, such as agriculture, urban runoff and wastewater discharge can fuel HABs by providing an abundant supply of nutrients such as nitrogen and phosphorus (Anderson *et al.*, 2012). Future scenarios indicate that continued nutrient pollution can exacerbate the occurrence and severity of HABs in coastal waters, leading to significant ecological impacts (Glibert *et al.*, 2014).

While our understanding of future scenarios of HABs on marine ecosystems continues to evolve, proactive measures to reduce nutrient pollution, enhance monitoring capabilities and improve ecosystem resilience are critical for minimizing the impacts of HABs on both ecological and human systems. HABs can have significant economic consequences. Commercial and recreational fisheries may experience declines or closures due to HAB-related fish kills or the accumulation of toxins in seafood affecting the livelihoods of coastal communities (Anderson *et al.*, 2012). The tourism industry in affected regions may also suffer from reduced beach access and water quality concerns associated with HABs. Consumption of contaminated seafood or exposure to HAB-affected waters can lead to various illnesses, including shellfish poisoning, respiratory issues and skin irritations (Hallegraeff, 2010).

Another key area of concern for water quality in marine ecosystems is plastic pollution (see **Chapter 2, sections 2.4, 2.6.2.4 and Box 2.7**). Future scenarios on the impact of plastics in the oceans and how this interacts with other nexus elements are in their infancy and research is needed to gain a comprehensive understanding of the long-term effects of plastic pollution. The quantity of plastic debris accumulating in marine environments is expected to increase in the future due to continued production and inadequate waste management practices (Jambeck *et al.*, 2015). Based on current trends, it is estimated that by 2050, there could be more plastic than fish in the ocean by weight (WEF *et al.*, 2016), with far reaching impacts on marine organisms and food production. Various initiatives and strategies are being implemented to address plastic pollution. These include promoting the circular economy, reducing single-use plastics, improving waste management and recycling infrastructure, and developing alternative materials. The success of these efforts will be critical in shaping future scenarios of plastic pollution in the ocean (UNEP, 2021).

Other drivers of change tested in marine scenarios relate to the effect of non-native or alien species arriving to a new ecosystem, in combination with other drivers such as resource exploitation through food provision (for example, by fishing) or climate change. Non-native species can have negative effects on habitat and thus ecosystem functioning, that can accelerate with climate change, or they can also play important roles as prey of commercial species, or even become commercial species themselves (Corrales *et al.*, 2018; Vilas *et al.*, 2021). Climate change and the associated ice melting in the Arctic is expected to lead to increased shipping traffic, potentially expanding ranges of non-native species and thus their impact on local ecosystems (Pratt *et al.* 2022). Further research is needed to develop scenarios of invasive species to understand where and when species are likely to expand their distributions and arrive in new areas due to climate change, and the implications of these range expansions on other nexus elements, such as biodiversity and food (IPBES, 2023a).

3.3.3 Scenarios focused on water demand

Water demand scenarios often involve trade-offs since they reflect allocation among sectors of a limited resource. The primary trade-off between water and other nexus elements is often with food production (Rockström *et al.*, 2014). By 2030, the irrigated area worldwide is expected to expand by 45 million hectares to meet food demand, an increase of almost 25 per cent (Krchnak *et al.*, 2011), with the agriculture sector continuing to be the largest consumer of water until 2050 (Rosegrant *et al.*, 2009). Alongside this, increasing demand is also expected from industry, domestic use, energy production and other sectors. Scenarios on water allocation between sectors in Europe show adverse effects of agricultural water demand on water availability for the domestic sector, manufacturing, electricity and aquatic ecosystems under climate and land-use scenarios in 2050 (Wimmer *et al.*, 2015).

Water demand scenarios also indicate impacts on health. In the Indian Sundarbans, groundwater demand showed trade-offs between water demand for food and the sustainability of coastal aquifer-dependent rural livelihood, with expected severe negative impacts on human health and well-being due to increased poverty, migration, drinking water salinization and other socio-economic shifts. In the East Africa region, freshwater shortages are impacted by human activities and expected to have future negative impacts on agriculture and livestock, along with health and social impacts (Payet & Obura, 2004). In western Australia, increased demand for groundwater was projected to result in the water table declining by up to 8 meters by 2030, leading to significant loss of biodiversity (Elmahdi & McFarlane, 2009). A scenario study on groundwater use from Canada highlighted trade-offs with hydropower generation and irrigation agriculture for both demand and supply (L. Wu *et al.*, 2021) but synergies with wind energy, greenhouse gas emissions and industrial water demand that reduced groundwater use by 2, 5.7 and 3.8 per cent, respectively. An alternative study in Syria showed that reducing pressure on water resources through sustainable groundwater management could reduce the risk of conflicts related to water (Gleick, 2014).

A few studies describe how ILK can enhance the development and assessment of scenarios for water resources management. Makondo & Thomas (2018) showed examples of how Indigenous practices related to water shortages, water level fluctuations and rainwater harvesting supported both health and biodiversity and could inform adaptation to climate change. To embrace ILK-based practices in water resources management, Reinhardt *et al.* (2018) show that the most useful scenarios assessments are transparent and based on individual, locally adapted procedures such as engaging local researchers and providing spatially explicit local information. Hosterman *et al.* (2023) used an inclusive process to select methods, including Indigenous metrics, to develop aquatic habitat restoration scenarios in the Lake Superior basin of North America to support wild rice (*Zizania palustris*), a cultural, ecological and food resource valued by the region's Indigenous Peoples.

3.3.4 Scenarios related to water supply

Dam construction is often a scenario for the future management of water supply. Dam construction scenarios often consider multiple nexus elements, with mixed impacts on these elements that vary spatially between upstream and downstream. Benefits include climate change mitigation and enhancing irrigation. Negative outcomes are found for downstream biodiversity and water uses leading to increasing vulnerability to drought (Cartes *et al.*, 2011; Lloret *et al.*, 2004; Yang *et al.*, 2018).

Other scenarios of water supply focus on flood mitigation and particularly nature-based solutions. Scenarios including grey and green infrastructure reduced flooding and agricultural production losses as well as the displacement of people due to environmental and health hazards (Pudar *et al.*, 2020). Other nature-based solutions scenarios such as retardation basins, infiltration/diversion and storage dams show how flood inundation can be effectively managed and filtration increased (e.g., Kuntiyawichai *et al.*, 2011; Jalilov *et al.*, 2018). Scenarios that reduce flooding also reduce flood-related risks to agriculture and health, while scenarios of nature-based solutions for flooding also promote biodiversity and ecosystem services. For example, sewage-related pollution and norovirus infection is expected to be higher with increased future flooding, making flood mitigation a key intervention for reducing these water quality and health risks (T. J. Wade *et al.*, 2014). Equitable management of trade-offs between water supply and water demand will be an increasing challenge under climate change.

3.4 FOOD-ORIENTED SCENARIOS AND THEIR NEXUS INTERACTIONS

This section synthesizes the scenario literature on food and its interactions with the other nexus elements of biodiversity, water, health and climate change. It focuses on three types of food scenarios: (1) food demand scenarios; (2) food supply scenarios; and (3) integrated food system scenarios.

Several scenarios have been developed on potential future impacts of drivers on food, as well as future implications of food demand and supply. Out of those 87 food-oriented scenarios were found that included an assessment of potential future interactions within the nexus (including 15 for food demand, 30 for food supply and 30 for integrated food systems). Most of studies relied on target-seeking (rather than exploratory) scenarios, and more than 60 per cent were of global scope with the remaining being of national or sub-national scope. All these scenarios were researcher-designed scenarios (rather than participatory scenarios) with no inclusion of ILK.

There are many options to mitigate the future impacts of the food system on both the consumption side (e.g., through dietary shifts) and the production side (e.g., improvement in land management) and many of them can have a significant impact on the future of biodiversity and other nexus elements. Changes in the food system can occur at various levels from production, processing and transportation to consumption and waste. Each of these levels have complex relationships with other nexus elements. For example, agricultural production contributes to biodiversity loss through habitat clearing, to freshwater and marine pollution through nutrient loading and to nutritional health by providing a healthy mix of nutrients. As such, how goals are set to achieve outcomes at each of these levels is critical for the overall nexus outcomes.

3.4.1 Impacts of multiple drivers on food

Multiple socio-economic drivers can influence future food systems, including population growth, economic growth, dietary preference and food-related technology development (Hinz *et al.*, 2020; Humpenöder *et al.*, 2022; Tallis *et al.*, 2018). Various food-related policies, such as free trade policies, may regulate production, food safety and other food system components on multiple scales (Alexander *et al.*, 2019; von Braun *et al.*, 2021). Furthermore, changes in environmental conditions, such as temperature, precipitation, rising carbon dioxide levels and nutrient and hydrological cycles can influence food production (Doelman *et al.*, 2022; Engström *et al.*, 2016; Hinz *et al.*, 2020).

BAU scenarios for food systems often estimate a steady increase in food demand, supply and agricultural land-use under these socio-economic and ecological drivers. Total food demand under "middle of the road" scenarios (e.g., Shared Socioeconomic Pathway 2 (SSP2), or the FAO's baseline scenario) is projected to increase by 51-98 per cent between 2005 and 2050 (Alexandratos *et al.*, 2012; Valin *et al.*, 2014; Van Dijk *et al.*, 2021). The demand for animal-based items may increase faster than for plant-based items, resulting in an increased share of livestock products to total food demand (Alexandratos *et al.*, 2012; Valin *et al.*, 2014). The total amount of food loss and waste may also increase with BAU scenarios (Bijl *et al.*, 2017; Lopez Barrera & Hertel, 2021). On the production side, the total production amounts for crops and livestock, agricultural land-use areas, and land-use intensity may increase under BAU assumptions, consistent with the changes in the demand side (Alexandratos *et al.*, 2012; Popp *et al.*, 2017).

3.4.2 Scenarios focused on food demand

Food demand can be characterised into two broad areas: (1) demand based on quantity of food, and (2) demand for variety or quality of food. Both have related but different impacts on other nexus elements and would also require different interventions. Food quality and variety also explicitly acknowledges different cultural demands for food, which tend to be ignored in models about total food demand. Demand for total quantity of food, without considering quality or variety of food, results in an increase in calories, which does not necessarily result in improved nutrition. Alternatively, demand for food variety can improve nutrition through consumption of diverse food items and balanced diets – rather than a focus on calorically dense foods with little nutrition. However, demand for variety can also increase demand for exotic foods motivated by sustainable healthy diets discourses which can lead to considerable negative telecoupled impacts, such as biodiversity loss in distant places (Lenzen *et al.*, 2012; Wilting *et al.*, 2017). Demand for food variety can also encourage demand for local varieties of foods, sometimes tied to cultural and sovereignty motivations, especially for IPLC. In some cases, IPLC have long maintained consumption of traditional and diverse crop varieties, contributing to species and genetic biodiversity conservation (Balemie & Singh, 2012) (see Appendix 7.1).

Consumption side scenarios primarily involve shifting dietary choices, reductions in overconsumption and reducing waste. The most well-studied food system nexus interactions in scenarios are between dietary change, biodiversity and climate change **(Box 3.4)**. Many studies highlight the impacts of dietary shifts from meat-intensive and highly-processed foods to a cluster of sustainable healthy diets often characterised by plant-based or less meat options (Henry *et al.*, 2019; Parodi *et al.*, 2018; Springmann, Clark, *et al.*, 2018; Springmann, Wiebe, *et al.*, 2018; Theurl *et al.*, 2020). These studies typically show that shifting diets from meat and other animal products to less meat, plant-based and alternative protein sources may be beneficial for biodiversity conservation, climate change mitigation and water withdrawal reduction (Doelman *et al.*, 2022; Henry *et al.*, 2019; Mosnier *et al.*, 2023b; Veerkamp *et al.*, 2020). Such dietary scenarios also often result in a positive impact on health. For example, the EAT-Lancet Commission proposes a planetary health diet – a flexitarian diet, which is mainly plant-based but can include modest amounts of fish, meat and dairy foods. The broad aim of the planetary health diet is to provide a sustainable healthy diet for 10 billion people in 2050, without overstepping global biophysical limits. It is estimated that adoption of this diet globally could prevent 19-24 per cent of total deaths per year among adults (Willett *et al.*, 2019), as well as reducing GHG emissions by 54-87 per cent (Springmann, Wiebe, *et al.*, 2018).

Box 3.4 Exploring pathways for sustainable land-use and food systems.

The Food, Agriculture, Biodiversity, Land-Use and Energy (FABLE) Consortium is a collaborative initiative created in 2017 that brings together independent interdisciplinary teams of researchers across 23 countries and all continents (FABLE, 2023). FABLE is the only bottom-up initiative for exploring food and land-use pathways at the global scale that takes account of the national context through stakeholder engagement, while factoring in international trade and fostering understanding of the collective responsibility across countries for meeting global targets (S. K. Jones *et al.*, 2023). It acknowledges the broad heterogeneity of socio-ecological contexts and demonstrates the urgent need for more collaboration and coordination to converge local and global priorities (Mosnier *et al.*, 2023a).

The adaptation of the models to fit the local contexts varies across countries. For instance, it can encompass the replacement of the input data from global datasets with country datasets (Navarro Garcia *et al.*, 2022; A. C. Smith *et al.*, 2023), the implementation of new features, e.g., representation of locally important crops or emission sources (Fuad *et al.*, 2020; Molla & Woldeyes, 2020), the calibration of key parameters to align model's results with historical statistics (Costa *et al.*, 2020; Jin *et al.*, 2020), and the improvement of the scenarios to better represent domestic policies (González-Abraham *et al.*, 2022; Jha *et al.*, 2022a; G. C. Wu *et al.*, 2022).

Results show that the achievement of the Paris Agreement, SDGs or the Kunming-Montreal Global Biodiversity Framework requires rapid and simultaneous changes across the world. Continuing current trends would lead to dangerous failure to ensure inter-generational justice, especially regarding climate and biodiversity **(Figure 3.5)** (FABLE, 2020; Mosnier *et al.*, 2023a). The implementation of a mix of levers was tested such as the adoption of sustainable healthy diets, productivity gains in agriculture, restrictions on future agricultural land expansion, reduction of food loss and waste, increased afforestation/reforestation and/or reduced population growth that could bring substantial benefits for multiple dimensions of sustainability (Mosnier *et al.*, 2023a; **Figure 3.5**).

Two-thirds of the country teams have assumed dietary shifts in the *Sustainable* pathway compared to *Current Trends* using national dietary recommendations (A. C. Smith *et al.*, 2023; González-Abraham *et al.*, 2022; G. C. Wu *et al.*, 2023), estimates from experts (Lehtonen & Rämö, 2022; Rasche, Schneider, *et al.*, 2022a) and/or international recommendations such as the EAT-Lancet Commission (Willett *et al.*, 2019). Shifts towards sustainable healthy diets could cut global greenhouse gas (GHG) emissions from Agriculture, Forestry and Other Land-Use (AFOLU) by half and reduce forest loss by 20 per cent over the period 2030-2050 compared to *Current Trends* (FABLE, 2021). In most countries, productivity gains are considered a means to achieve higher sustainability even if all productivity assumptions result in a lower global annual average productivity increase than the growth observed between 1990 and 2010. In the FABLE modeling framework, crop and livestock productivity increases led to significant land sparing that could be used for nature restoration (FABLE, 2022b). Some countries also include targets on adoption of specific farming practices (Perez-Guzman *et al.*, 2022; Rasche *et al.*, 2022). Basnet *et al.* (2023b) show that in Sweden, expansion of organic farming consistent with their national target would require dietary changes and reduced food waste to improve national food self-sufficiency, biodiversity conservation and reduce GHG emissions. While net zero climate commitments from countries cover nearly 90 per cent of current GHG emissions, achieving net zero GHG emissions from agriculture and land by 2050 generally involves halting deforestation immediately or at least before 2030, while increasing afforestation efforts (F. Frank *et al.*, 2023; Costa *et al.*, 2020; Jha *et al.*, 2022b; FABLE, 2022a).

Stronger policies and incentives will help enable all stakeholder groups to participate and support the transformative change process. These and other mechanisms for applying sustainability levers need to be implemented with care and tailored to each country's local context to ensure that benefits and trade-offs are fairly and equitably distributed (S. K. Jones *et al.*, 2023).

Box 3 4

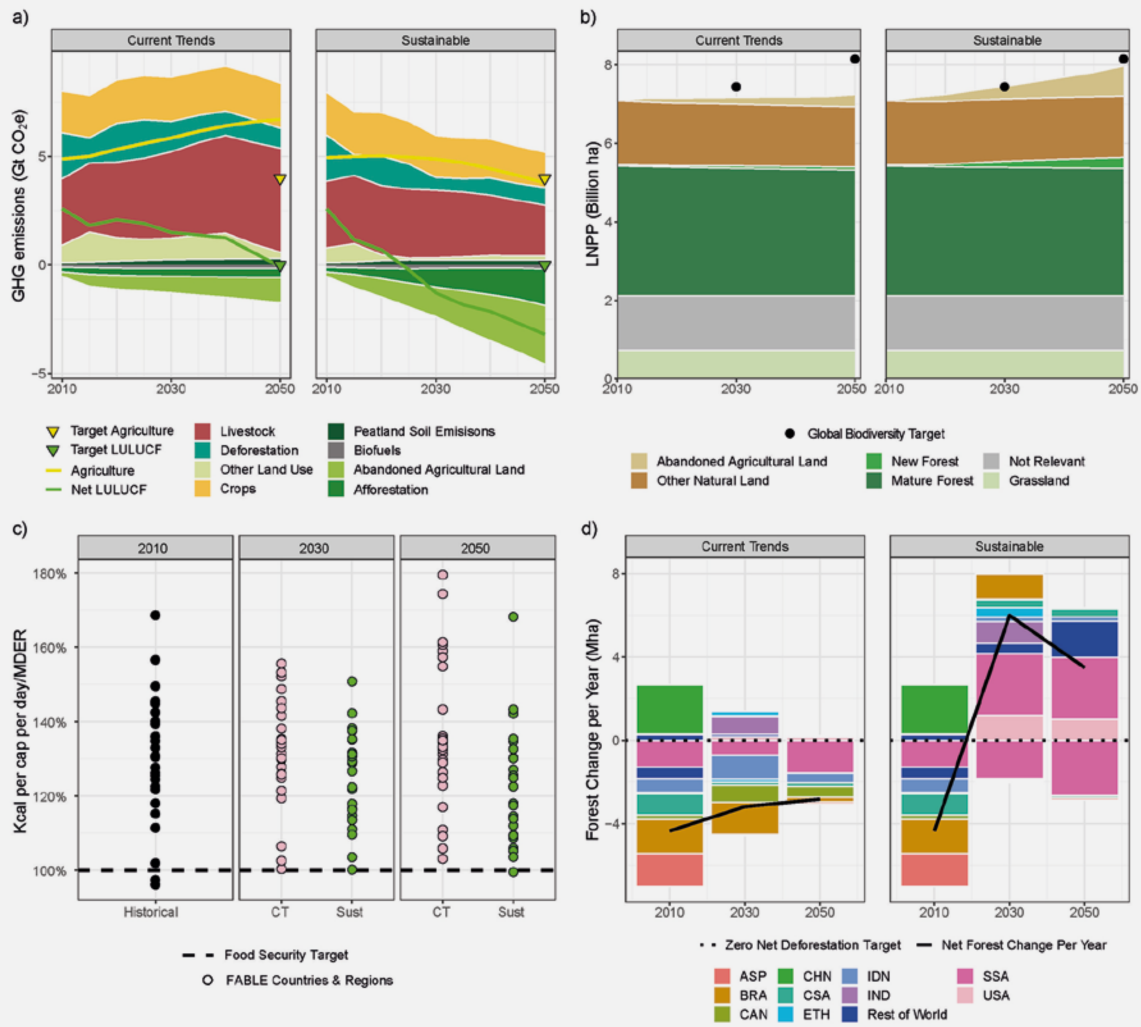


Figure 3 5 **Modelling results for *Current Trends* and *Sustainable* pathways from the FABLE consortium.**

a) GHG emissions; b) land where natural processes predominant (LNPP) as an indicator of biodiversity; c) average daily kilocalorie consumption per capita; and d) annual forest change. Notes: LNPP refers to land where there is a low human disturbance and/or ecologically relatively intact vegetation, providing space and habitat for biodiversity to thrive (FABLE, 2022b); average daily kilocalorie consumption per capita excludes food waste at the household level; MDER is average Minimum Daily Energy Requirement per country and region; BRA – Brazil, CAN – Canada, CHN – China, ETH – Ethiopia, IDN – Indonesia, IND – India, ASP – Asia and Pacific, CSA – Central and South America, SSA – Sub-Saharan Africa, RoW – Rest of the World; countries and regions can simultaneously have gains and losses in the forest area that are shown separately in the figure.

Source: Mosnier *et al.* (2023a) under CC-BY-4.0.

Dietary shifts can be contentious. Discussions about which type of diet is suitable for which place (Davies *et al.*, 2023; Kimani-Murage *et al.*, 2021; Kozicka *et al.*, 2023), affordability of specific diets and sociocultural suitability are important considerations. Furthermore, plant-based diets are not always the answer for all places and sometimes reducing meat consumption is more climate-friendly than eliminating meat when replacing a large share of meat's protein with dairy (B. F. Kim *et al.*, 2020). Nonetheless, current food systems and associated diets need transformation within the broader global goals, but in ways that recognize cultures, geographical constraints and other contextually relevant phenomenon. Despite studies showing the synergistic interactions between dietary shifts and biodiversity, trade-offs are also observed in developing countries, especially with regards to food production and conservation priorities (Henry *et al.*, 2022; Rasche, Habel, *et al.*, 2022).

In addition, there is the potential for negative impacts on biodiversity if dietary shifts lead to increases in the production of plant-based proteins in tropical regions (Henry *et al.*, 2019). Countering this, reductions in livestock numbers due to reduced intake of animal-based foods would reduce the demand for plant proteins such as soy for use as animal feed as well as the land area used for pasture (Cassidy *et al.*, 2013; Poore & Nemecek, 2018), but could increase its demand as a protein source for human consumption. A shift to sustainable healthy diets combined with sustainable harvesting, reforestation and halting deforestation widens the potential for net negative GHG emissions from agricultural sectors (Theurl *et al.*, 2020).

Emerging food technology, including various meat alternatives, may also have the potential to influence future diet change and subsequently, future biodiversity and climate change (Zurek *et al.*, 2021). By some estimates, substituting 20 per cent of per-capita ruminant meat consumption with microbial protein globally by 2050 could offset future increases in global pasture area, cutting annual deforestation and related CO_2 and methane emissions (Humpenöder *et al.*, 2022). The long-term impacts of these alternative proteins are yet to be fully understood, and in some instances they have been shown to have similar energy use as conventional protein sources (Thornton *et al.*, 2023). In addition, they are likely to face an uphill battle to be culturally accepted as legitimate sources of protein in some contexts, and would require dedicated efforts to facilitate their adoption.

The impact of future dietary change on water systems can be dependent on context and scale. Shifting to a low-meat diet can have synergies with water systems globally, as it can reduce irrigation water withdrawals and protect or restore hydrological environmental flows (Doelman *et al.*, 2022). Scenarios of lower animal product consumption greatly reduce agricultural expansion in regions of high biodiversity and the amounts of water applied to cropland in the tropics compared to the BAU scenario (Henry *et al.*, 2019). However, such dietary shifts can result in increased freshwater use in some countries and regions (Springmann, Wiebe, *et al.*, 2018; Tuninetti *et al.*, 2022). The adoption of these diets is estimated to reduce the water footprint by 12 per cent globally but may increase water consumption up to 40 per cent in 54 countries (Tuninetti *et al.*, 2022). These mixed outcomes for water from dietary shifts are even more pronounced at different geographic scales (Candy *et al.*, 2019; Tuninetti *et al.*, 2022).

Reducing food loss and waste is a cross-cutting theme that also applies to demand-side scenarios, and it is often examined for its potential impact on lowering multiple environmental impacts. Scenarios reducing food loss and waste by half, aligned to commitments under the SDGs, would reduce GHG emissions by 7 per cent, cropland use by 17 per cent, and bluewater use by 16 per cent, compared with the 2050 baseline scenario (Springmann, Clark, *et al.*, 2018; Van Vuuren *et al.*, 2019).

3.4.3 Scenarios focused on food supply

Food production systems are major drivers of biodiversity loss, both on land and in the sea, indicating an intricate connection between land and sea ecosystems. The land-sea connection is often overlooked in scenarios exploring possible futures about the food system. These hidden interconnections could be exemplified by agricultural runoff flowing into coastal and marine ecosystems and negatively affecting marine system quality – or fish from marine systems as human food. These connections are further compounded by climate change impacts on the food system, and food system impacts on climate change, creating a feedback loop between food and climate systems.

3.4.3.1 Terrestrial realm

How and where food is produced to meet current and future food demand affects biodiversity, climate change and water systems. Changes from unsustainable food production practices to sustainable production alternatives could help achieve habitat protection, reduce GHG emissions consistent with the Paris Agreement and reduce water stress (Tallis *et al.*, 2018). Some estimates suggest that the current global agricultural area has the capacity to feed 3 to 20 billion people depending on human dietary patterns, land-use changes and nitrogen management (Chatzimpiros & Harchaoui, 2023). Under an industrial fertilization scenario, the global feeding capacity is estimated to be 8 to 20 billion people, whereas under an organic fertilization scenario the present agricultural area is estimated to be able to feed 3 to 14 billion people. This implies that the existing agricultural area could feed the future human population, which is predicted to be 9.7 billion in 2050 and 11 billion in 2100, using sustainable agricultural practices combined with changes in human diets that assume reduced animal protein and optimal crop food-feed ratios (Xia & Yan, 2023). Improvements in nitrogen use efficiency from the current level (35 to 44 per cent) to 70 to 80 per cent are key to improving food yield (Chatzimpiros & Harchaoui, 2023).

Other interventions include replacing cropland-based animal feed with the industrial production of microbial protein to decrease cropland area, nitrogen losses from croplands and agricultural GHG emissions globally (Pikaar *et al.*, 2018). However, knowledge on the impacts of industrial feed production is still limited, and the possible trade-offs and synergies are therefore unknown.

Existing policy options have relied on agricultural extensification by expanding lands for food production often at the expense of biodiversity-important areas such as natural forests, woodlands and savannahs. Scenarios of land-use change, such as expansion of palm oil production, have been shown to have various impacts on the other nexus elements, such as high deforestation rates, large carbon emissions due to plantations and losses of habitat and threats to biodiversity (Rulli *et al.*, 2016). Scenarios focused on agricultural intensification can reduce the overall pressure on rangeland biodiversity, but these need to be complemented with additional measures to address factors such as climate change (Alkemade *et al.*, 2013). The outcomes of intensification are however not always straight forward. A study in India showed that enhancing productivity by 2030 would have a positive effect on the rates of CO_2 uptake but a negative effect on biodiversity compared to the reference scenario (Hinz *et al.*, 2020). Agricultural intensification can also result in trade-offs among the nexus elements in some regions, such as negative impacts on biodiversity due to water pollution, water cycling alteration and eutrophication.

As demand for bioenergy increases, competition for land between food and energy in the future can also affect the relationships among nexus elements. Under current assumptions of future food requirements, it is not possible to produce significant amounts of first-generation bioenergy without cropland expansion (N. Bauer *et al.*, 2020; Henry *et al.*, 2018). Increasing dependence on biofuels would have antagonistic effects on food provision and the diversion of energy sources from biofuels might compete with food production, particularly in high quality arable land (Calvin *et al.*, 2021; P. Smith *et al.*, 2020). The production of biofuels uses 2 to 3 per cent of global water and land which otherwise could be used to provide food to about 30 per cent of the malnourished population (Rulli *et al.*, 2016). As both food and bioenergy demands are expected to increase in the future, careful design of policies is critical to balancing production of both these sources, without compromising the provision of food or energy.

3.4.3.2 Freshwater and marine realms

There are three key food aspects within freshwater and marine realms: fish and shellfish aquaculture, wild fisheries and seaweed. These components make a crucial contribution to global food security, nutrition and livelihoods from inland, freshwater and marine ecosystems (FAO, 2022; Hicks *et al.*, 2019).

The environmental effects of aquaculture (including mariculture, which specifically involves the farming of marine species, **Box 3.5**) are complex and interconnected with capture fisheries due to their dependency on wild fish stocks and pressure on forage species. Sustainable marine aquaculture is viewed as a potential alternative to deteriorating fish stocks and as such is expected to grow in the future (FAO, 2020; Gephart *et al.*, 2021). However, in the coming decades, some regions will face potentially greater climate change challenges affecting the resilience and growth potential of marine aquaculture by geographic location (Froehlich *et al.*, 2018; Klinger *et al.*, 2017). Fisheries have a unique position in the nexus as fish and other aquatic plants and animals are characterized both as biodiversity and food. Fisheries and marine ecosystems can also be significantly affected by future climate change (Lotze *et al.*, 2019; Tittensor *et al.*, 2021), with projections of impacts on catch being more negative under pessimistic scenarios of climate change (RCP8.5) than under more optimistic ones (RCP2.6) **(Box 3.5)**.

Box 3 5 The future of food from the ocean.

Food from the ocean (also often termed “blue food”) already contributes significantly to global food security, nutrition and livelihoods through fisheries as well as mariculture of fish, shellfish and seaweed (Hicks *et al.*, 2019). However, projected interactions between climate change and biodiversity are likely to affect food availability through species- and region-specific changes in the distribution and production of target species. Sustainable management and marine spatial planning can help avoid some of the projected impacts.

By 2100, under business-as-usual scenarios, fisheries catch potential at global and regional levels are projected to decrease (Cheung *et al.* 2010, 2012), including when converted to biomass of commercial species (Coll *et al.*, 2020) or consumer biomass (Lotze *et al.*, 2019, Tittensor *et al.*, 2021). The negative projections are high under pessimistic scenarios of climate change (RCP8.5) and moderate under more optimistic ones (RCP2.6) with trophic amplification. In addition, projections have large spatial heterogeneity revealing winners and losers (Cheung *et al.*, 2010; Coll *et al.*, 2020). Within exclusive economic zones (EEZs), exploited fishes and invertebrates are projected to decrease in biomass overall, as is maximum catch potential for high temperature extremes. Net negative impacts on fish stocks are projected to cause losses in fisheries revenues and livelihoods in most maritime countries, creating shocks to fisheries social-ecological systems particularly in climate-vulnerable areas. Effects of climate change and fishing vulnerability are exacerbated in some deep-sea fishes because of their life history traits, such as slow growth, late maturity and late onset of reproduction (Cheung *et al.* 2022). Some groups, such as cephalopods and mesopelagic fish, which have been associated with important ecosystem services, emerge as

Box 3 5

potential winners under future scenarios of climate change and fishing (Coll *et al.*, 2020).

To achieve sustainable fisheries, scenario testing shows that combinations of management measures are needed, including the reduction of fishing effort and mortality, and the placement of marine protected areas (MPAs) and fisheries restricted areas. These management measures can be implemented in different ways (Gomei *et al.*, 2021) but their effectiveness is key to ensuring success in rebuilding resource fisheries (Vilas *et al.* 2021a). However, climate change is projected to potentially jeopardize the outcomes of these management measures (Corrales *et al.*, 2018; Vilas *et al.*, 2021a). Scenarios show that fisheries management under Harvest Control Rules can reduce the impact of high temperature events on fish catches relative to Open Access and will be most effective in regions that are projected to be hit hardest (mostly in developing nations) (Cheung *et al.*, 2021). Countries with low adaptive capacity but increasing demand for food may require greater support and capacity building to transition towards reconciling trade-offs (Blanchard *et al.*, 2017; Cinner *et al.* 2022). Modelling results suggest that the necessary actions are context-dependent and include effective governance, improved management and conservation, maximizing societal and environmental benefits from trade, increased equitability of distribution and innovation in food production, including continued development of low input and low impact aquaculture (Bryndum-Buchholz *et al.*, 2019; Blanchard *et al.*, 2017).

Potential tools to conserve and manage fisheries include area-based management tools intended to protect key elements of marine ecosystems to contribute to the recovery of habitats and species. Area-based management tools protect Vulnerable Marine Ecosystems (VME) from the impact of fishing in the deep-sea and Essential Fish Habitats (EFH), when integrated in an ecosystem-based approach, and have proven effective for managing fisheries and improving ecosystem health (Mcconnaughey *et al.*, 2019). Frameworks to develop future scenarios that include the protection and restoration of VMEs and EFHs while ensuring sustainable fishing are starting to emerge (Hamon *et al.*, 2021; FutureMares 2021), although they are still mostly lacking in the scientific scenario literature.

In the Arctic ocean, ecosystems are projected to undergo drastic changes as climate warms, ice melts and access by humans becomes easier. For example, changes in the distribution and abundance of native seaweeds, associated invasive species, invertebrates and fish have been projected (e.g., (Campana *et al.*, 2020; Filbee-Dexter *et al.*, 2019; Goldsmit *et al.*, 2020; Vilas *et al.*, 2021), some facilitated by increased ship traffic (Pratt *et al.*, 2022). Consequently, associated interactions with small scale fisheries are projected to impact the food security and health of Indigenous Peoples. MPAs have been proposed (World Wildlife Fund, 2023) and in some cases implemented (e.g., Tuvaijuittuq MPA in Canada; Government of Canada, 2023); however, projected outcomes of protection on the interactions between biodiversity, climate change, health and food are not known.

Scenario studies have also explored the growth potential for sustainable fish mariculture as a potential alternative to continuing deteriorating fish stocks. For example, Klinger *et al.* (2017) show that the growth potential for fish mariculture varies among species and geographic locations by 2050. Based on individual species growth rates, some areas will become or remain physically suitable after climate change for expanding mariculture. However, this growth will be constrained economically in developing nations (Klinger *et al.* 2017). Countries with less affected maricultural sectors could add stability through trade (Froehlich *et al.*, 2018). For invertebrates, synergistic effects of climate drivers (e.g., temperature, precipitation, erosion, freshwater input) with mariculture drivers (focal cultured species) can lead to more negative outcomes (Filgueira *et al.* 2016). Increasing food production (i.e., bivalve biomass) can destabilize the ecosystem through multiway interaction with significant spatial variation in the outcome (Chapman *et al.* 2020).

Seaweed mariculture is gaining momentum globally, with the largest production in China, Japan and Indonesia and smaller volumes in Korea, North and South America and Europe. Mariculture seaweed is being used for food but also processed into food additives and nutraceuticals, feeds, fertilizers, biofuels, cosmetics and medicines (Buschmann *et al.* 2017). Global seaweed production volume is expected to continue to increase, providing direct benefits to support several SDGs (Duarte *et al.* 2022). The magnitude of opportunity for seaweed aquaculture can vary geographically, being higher in temperate regions for a scenario which optimizes environmental health and socio-economic factors. High opportunity has also been shown in several tropical regions for scenarios when socio-economic or health factors alone were considered (Theuerkauf *et al.* 2019). Addressing biophysical and socio-economic constraints for 34 species of seaweed, Spillias *et al.* (2023) estimated that only 1.8 per cent of the ocean surface would be suitable for cultivation. They estimated that less than 215 Mha of sea-use are needed to meet three goals by 2050: (i) seaweeds form 10 per cent of global diet; (ii) seaweeds make up 10 per cent of global livestock feed for ruminants, poultry and swine by energy content; and (iii) seaweeds constitute 50 per cent of the feedstock used to produce transport fuels. The largest amount of suitable habitat was found in the Indonesian EEZ, which could replace 250 Mha of agricultural land, with concomitant savings in water used for irrigation (>80 km^3 per year) and fertilizer (>35 Mt per year) (Spillias *et al.* 2023).

Future scenarios also consider the need for resilience and adaptation in the face of environmental and social challenges, and consider strategies to enhance resilience, such as diversifying species, adopting sustainable mariculture systems and integrating climate change considerations into management and planning (Merino *et al.*, 2012; Troell *et al.*, 2014). Future scenarios for integrated food systems in fisheries and

Box 3 5

mariculture highlight the complex and interconnected nature of fish production and stress the need for integrated approaches to ensure food security and environmental sustainability in the face of a changing climate (Merino *et al.*, 2012). They also recognize the importance of social and economic factors, including considerations of equity, livelihoods, food security and the well-being of fishing and aquaculture communities (Bush *et al.*, 2019; FAO, 2022). Balancing economic development with environmental sustainability and social inclusivity is a crucial aspect of shaping the future of these sectors to continue contributing to food security in the face of climate change.

To sustainably meet increasing global demands for food from the ocean, the interlinkages among goals within and across fisheries, and the mariculture and agriculture sectors must be recognized and addressed along with their changing nature (Blanchard *et al.*, 2017). Some countries are likely to face double jeopardies in both fisheries and agriculture sectors under climate change (Blanchard *et al.*, 2017; Cinner *et al.* 2022). The strategies to mitigate these risks will be context-dependent and will need to directly address the trade-offs among SDGs, such as halting biodiversity loss and reducing poverty.

3.4.4 Scenarios focused on integrated food systems

Integrated strategies of dietary shift, reduced food waste and losses, agricultural intensification and crop selections can provide additional benefits to biodiversity conservation, climate change mitigation and the reduction of other environmental impacts **(Table 3.2)**. While a change in dietary habits may be sufficient for preservation of natural intact vegetation in many hotspot regions, a sustainable healthy diet may put more pressure on natural intact vegetation in other hotspot regions (Rasche, Habel, *et al.*, 2022). There is increasing evidence to suggest that transformative change in the whole food system is needed to deliver healthy nutritional outcomes for a growing population while simultaneously ensuring environmental sustainability (Lee *et al.*, 2019). Agriculture, including its role in deforestation, is one of the largest contributors to the loss of terrestrial biodiversity up to 2050, while increased productivity by technological improvements (e.g., increasing nutrient use efficiency), increased use of ecological methods in agriculture and forestry and consumption changes help to avoid biodiversity loss (Kok *et al.*, 2018). There are estimates that by 2050, more than two thirds of future biodiversity losses could be avoided through sustainable intensification and trade, reduced food waste and diet shift to a lower share of animal calories (Leclère *et al.*, 2020). Ultimately, a combination of proactive approaches and policies targeting how, where and what food is produced could potentially prevent almost all the losses in biodiversity, while contributing to sustainable healthy human diets (Williams *et al.*, 2021).

Scenarios with agricultural intensification combined with diversified environmental protection policies, show reduced impact of land-use and land cover change on vertebrate species richness and conservation of natural habitats (Göpel *et al.*, 2020). Similar scenario studies have shown that at least a 15 per cent yield improvement or a substantial reduction in meat consumption by the 2050s is required to maintain food imports at today's levels and avoid the potential displacement of food production and deforestation (Lee *et al.*, 2019). Country-level studies **(Box 3.4)** show that scenarios with low meat consumption, less food waste and high agricultural productivity can result in lower GHG emissions and higher values in biodiversity indicators than a current trends scenario (F. Frank *et al.*, 2023; Perez-Guzman *et al.*, 2023; A. C. Smith *et al.*, 2023). However, other studies have shown the reverse, where for example, cattle grazing would help maintain semi-natural pastures that are rich in biodiversity (Basnet *et al.*, 2023b).

Changes in consumer choices in Europe, North America and Oceania and in the supply-chain in Africa and west and central Asia have the greatest potential to reduce the land footprint of the food system (Alexander *et al.*, 2019). Furthermore, food system changes are subject to political and public constraints that usually allow only gradual, incremental changes to occur, rather than transformation. Stylistic scenarios have shown that marginal food system changes (i.e., incremental changes) to increase production efficiency, reduce losses or to adjust diets could collectively reduce the agricultural land required globally for food production by 21 per cent, or over a third given higher adoption rates, which would provide considerable scope for nature conservation and GHG emission reduction (Alexander *et al.*, 2019).

Global level scenarios often miss the fine-grained food values and concerns held by IPLC **(Box 3.6)**. For example, a study in Thailand (Kupkanchanakul *et al.*, 2015) demonstrates how the use of local knowledge and local management practices can be used to develop realistic nutrient management scenarios. Other subnational and local considerations include amplifying the use of underutilized crops (Chivenge *et al.*, 2015). These crops might have other benefits including indigenous crops in sub-Saharan Africa that use less water, which could be a key adaptation approach for adjusting to water scarcity given climate change impacts on food production (Chivenge *et al.*, 2015).

Table 3 2 **Illustrative scenarios focused on food and the outcomes for the nexus elements.**

Scenario	Scenario description	Outcome for nexus elements				
		Food	**Biodiversity**	**Climate**	**Water**	**Health**
Business-as-usual (BAU)	No additional food-related actions	Increasing food demand, including meat demand; increasing food waste; expansion and intensification of cropland and pasture	Negative outcomes on global biodiversity from habitat conversion and overexploitation	Unabated global warming to +2.8°C or more	Increasing water withdrawal and pollution	Inadequate nutrient supply: increases in chronic diseases and premature mortality
Food-based sustainable development pathway	Integrated strategies of dietary shift, reduced food waste, agricultural intensification and crop selections	Plant-based or sustainable healthy diet; reduced food waste; sustainable intensification; relocation of crops and production areas	Provides space for conservation; reverses global biodiversity trends to be positive in the long-term	Limited global warming well below +2°C	Limited water withdrawal and pollution	Adequate nutrient supply: reductions in chronic diseases and premature mortality
	Multifunctional land uses/ agroecology	Maintain domestic food availability; increased agricultural productivity, diversified food sources	Increases in biodiversity	Increases in climate adaptation options		Increases in medicinal products

Box 3 6 ***Scenarios of climate change impacts on seafood biodiversity, harvest and health of First Nations in British Columbia, Canada.*** [3]

First Nations are among the original inhabitants along the Pacific coast of Canada and include 203 of the 634 unique First Nations/Indian Bands in the country. Small-scale fisheries have played a fundamental social, cultural and economic role for these Nations who have managed them to ensure long-term resilience over millennia. Climate change is putting at risk these resources and the various roles they play in First Nations communities, yet quantitative scenarios of projected impacts on small scale fisheries are not common.

Two recent studies (Marushka *et al.*, 2019; Weatherdon *et al.*, 2016) have combined quantitative models on climate change, generated by western science, with ILK on fished and consumed species to examine potential impacts on catch potential and nutritional requirements. (Weatherdon *et al.*, 2016) selected 16 First Nations on coastal British Columbia to represent differences in resources, geography, territorial size and treaty status. Ninety-eight selected species harvested for food, social and ceremonial purposes included marine and diadromous fish, shellfish and invertebrates. Using a combination of species distribution models and dynamic bioclimate envelope models, changes in the abundance of each species driven by change in ocean properties under climate scenarios RCP2.6 and RCP 8.5 were projected for the period 2041 to 2060 compared to 1991 to 2010. Most species declined in abundance under both scenarios and showed a poleward shift in distribution, with a consequent latitude-dependent decline in catch potential for several fisheries. Specifically, the Pacific herring and the Pacific salmon commercial fisheries were projected to decrease by 28 to 49 per cent and 17 to 29 per cent by 2050, leading to a 16 to 29 per cent estimated reduction in revenue. Some of these declines could conceivably be offset by equitable resource sharing agreements between Nations but for two challenges: most species in the southern territories are expected to decline, thus providing no alternatives to offset, and these agreements have been mostly local rather than regional.

Using the projected changes in species abundance, distribution and catch potential, (Marushka *et al.*, (2019) & Weatherdon *et*

3. Common case study highlighting Indigenous Peoples' and local communities' (IPLC) food systems. See **Chapters 1**, **2**, **4**, **5.1** to **5.5** and **6** for additional IPLC food system case studies. Lessons learned from the common case studies are presented in **Chapter 7**, online **Supplementary material 7.1**.

Box 3 6

al., (2016) used household dietary data from six First Nations communities to assess food security and traditional food gathering activities and the consequent impacts on nutrition of three scenarios of simplistic replacement of lost seafood: (i) an alternative land protein source (chicken); (ii) an alternative marine protein source (canned tuna); and (iii) an energy source (bread). Among the respondents, salmon and halibut were the most consumed species, followed by herring roe and prawns. Shrimp and herring were projected to experience the largest declines by 2050 and sockeye salmon and herring were projected to decline by 10 to 36 per cent and 12 to 13 per cent, respectively. Consequently, an overall decline of 20 to 30 per cent in the overall contribution of seafood to the Dietary Reference Intake was projected for 2050, particularly nutrients primarily obtained from seafood, such as n-3 fatty acids and vitamins D and B12. Partial or inadequate replacement of these nutrients could be achieved by simplistic replacements from different sources.

Because of the cultural significance of salmon, First Nations living along the Fraser, Skeena and Nass Rivers are particularly concerned about key threats further endangering future salmon populations, with climate change being the second highest after aquaculture (Reid *et al.*, 2022). To improve fisheries management for both stewardship and harvest, members of Haíłzaqv nation overwhelmingly supported the reintroduction of communally run terminal fisheries (near or at the terminus of the migration) and for Haíłzaqv laws to guide the management of salmon fisheries within the territory (Steel *et al.*, 2021). The development of co-led spatial management plans based on ecosystem-based management has provided an opportunity for First Nations to engage with, and contribute to, the knowledge, design, implementation and governance for managing marine activities and resources in the region, as well as developing regional risk assessments for ocean climate (Diggon *et al.*, 2022; PNCIMA Initiative, 2017). Ultimately, despite the profound impacts to the rhythms of the Earth, the relationships of Indigenous Peoples with the land, as well as their activities, practices and ceremonies related to caretaking of land and waters persist, highlighting the importance of upholding their rights to self-determination and food sovereignty (Turner & Reid, 2022).

3.5 HEALTH-ORIENTED SCENARIOS AND THEIR NEXUS INTERACTIONS

This section synthesizes the scenario literature on health and its interactions with the other nexus elements of biodiversity, water, food and climate change. It focuses on two types of health scenarios: (1) scenarios of infectious diseases, vector-borne diseases and zoonoses; and (2) health effects of urban green and blue spaces. Note that evidence from scenarios of dietary health are presented in **section 3.4** from the perspective of both the food and health nexus elements, while evidence from scenarios covering water and health in the freshwater realm are presented in **section 3.3**.

Several scenarios have been developed on potential future impacts of drivers on health. However, while overall targets linking health with other nexus elements, in addition to climate change, are being discussed, studies of health using a nexus approach are generally lacking and health scenarios considering nexus elements are rarely found in the literature. Health is mostly considered using climate scenarios (e.g., habitat suitability of vectors and vector-borne diseases), land-use scenarios (e.g., spillover risk of zoonoses) and scenarios on air pollution (e.g., respiratory and cardiovascular diseases, lung cancer). Studies examining future disease burden related to dietary risks are much less common. Health outcomes, such as injury, diabetes and metabolic syndromes, developmental disorders and mental illness, are not studied at all in future projections under changing environmental risks (Weber *et al.*, 2023).

In this section, health-oriented scenarios from 18 studies were identified that included an assessment of potential future interactions within the nexus. Approximately 50 per cent of these studies covered the global scale, while the local to national studies covered all IPBES regions except for Africa. Most of the studies originated from academia and provided quantitative results, while the proportion of exploratory and target-seeking scenarios was roughly equal.

3.5.1 Impacts of multiple drivers on health

The assessments of future impacts of multiple drivers on health in the context of the nexus primarily focus on health aspects such as life expectancy. For example, the impact of linked changes in population, gross domestic product, climate change, water quality, dietary change and land-use on trends in average life expectancy in 2030, 2050 and 2100 was simulated by a global system model (Moallemi *et al.*, 2022). Under the most optimistic Green Recovery scenario (SSP1-2.6), life expectancy improved for approximately 50 per cent of simulations at each time point, but these trends fell short of stated moderate targets of life expectancy increase (Moallemi *et al.*, 2022).

Considerable recent attention has been paid to the COVID-19 pandemic and its relationship to nexus issues, as most pandemics are caused by pathogens of animal origin (Judson & Rabinowitz, 2021). Future changes in zoonoses and infectious disease risks are expected due to diverse indirect and direct drivers of change. Specifically, increases in the world population are projected to lead to increases in human animal contacts through land-use change, agricultural expansion at the fringes of natural ecosystems, trade and consumption in animals and animal products (both domestic and wild), and increased populations of farmed animals. For SARS-CoV-2, for example, substantial evidence points to a likely origin where the greatest diversity of SARS-related coronaviruses is found (Latinne *et al.*, 2020), where contact among people and bats is common (H. Li *et al.*, 2019; H.-Y. Li *et al.*, 2020), and where human populations are expanding and encroaching into a rapidly changing landscape (Rulli *et al.*, 2021). With increased animal farming, emerging diseases are expected to increase due to spillover between wildlife and farm animals (Morse *et al.*, 2012), e.g. SARS-CoV-2 (Sikkema *et al.*, 2022), and vice versa, with possible devastating effects (e.g. HPAI H5 (Verhagen *et al.*, 2021).

Climate change will also shift ranges of people, wildlife, reservoirs and vectors, and with them the pathogens they harbour and temperature dependent transmissions risks. Scenarios of infectious diseases and zoonoses mostly consider climate change scenarios, which are applied to project the spatio-temporal distribution of different species in the transmission cycle (e.g., Samy *et al.*, 2022) or direct occurrence of disease cases (e.g., (Messina *et al.*, 2019; Tjaden *et al.*, 2021). Human population density is mostly considered as a constant factor over time as spatially high-resolution projections of population are missing (Zhiwei Xu *et al.*, 2020). Climate change adaptation/mitigation measures in the form of water catchments, urban green spaces or peatland restoration can result in possible habitats for disease vectors of arthropod-borne diseases. Melting glaciers and permafrost reactivate and release pathogens into aquatic and terrestrial environments immured for millennia as shown by recent outbreaks (e.g. Siberia, Russian Federation) (Yarzábal *et al.*, 2021).

Another driver affecting health in futures-oriented studies is pollution from human activities. For example, for the marine realm, a warming climate can further influence the geographical distribution and availability of ocean pollutants though release of legacy pollutants (e.g., plastic waste, pharmaceuticals, toxic metals, fertilizer, pesticide and sewage constituents) previously trapped in ice and permafrost (Allen *et al.*, 2019). Pollution-sourced microplastics could become problematic vectors of disease by transporting and sheltering marine pathogens. Also predicted is expansion in the geographic range of bacteria that thrive in warmer waters, such as the disease competent *Vibrio* species (Vezzulli *et al.*, 2016). Human and veterinary pharmaceutical use continue to increase globally, because of population growth, rising per capita consumption and growing livestock. The antimicrobial resistance associated with the presence of antibiotics in the environment (e.g., in surface and sewage water) is likely to worsen (Wöhler *et al.*, 2020). Interlinkages between drivers such as eutrophication, temperature and salinization can also act directly on the mosquito larval habitat, or with secondary soil salinity of drylands, resulting in large and often underestimated impacts on mosquitoes (e.g., *Culex pipiens* s.l. (Boerlijst *et al.*, 2023); *Aedes camptorhynchus* (Jardine *et al.*, 2008)).

Limited quantitative estimates of health impact are available for BAU scenarios, particularly in terms of linking climate change projections and health. Under current GHG mitigation policies, global average temperatures reach 1.5°C in the near-term and 2°C by the 2050s, leading to a doubling of multi-sector risks (Byers *et al.*, 2018). Climate change is projected to have net negative effects on malnutrition, heat-related human mortality and morbidity, food-borne, water-borne and vector-borne diseases, and mental health challenges (IPCC, 2022a). Compared to BAU, scenarios designed to achieve ecological and health benefits are projected to substantially reduce mortality rates (Hamilton *et al.*, 2021).

The impacts on health of combined changes in biodiversity, water, food and climate change have not been quantified, but are likely to be severe, even if major social or ecological discontinuities can be avoided. Quantitative models of global health generally depend on individual risk factors and socio-economic trends and do not yet account for interactions across the nexus. Conversely, models investigating impacts of global environmental changes on health typically do not account for socio-economic or health system changes (Weber *et al.*, 2023).

3.5.2 Scenarios of infectious diseases, vector-borne diseases and zoonoses

3.5.2.1 Terrestrial realm

Spillover of pathogens due to contact among wildlife, livestock and people is the starting point of zoonoses which account for 70 per cent of all emerging diseases in humans such as COVID-19, Ebola and Zika (IPBES, 2020). The global pattern of zoonotic hazard is similar to the global pattern of species richness but inter-regional and local differences in the zoonotic hazard index suggest that land-use impacts should not be neglected (García-Peña *et al.*, 2021). For example, (Rohr *et al.*, 2020) simulated the presence of rodent taxa combined with rodent capacity of transmitting zoonotic pathogens in the short (2025) and long-term (2050) under three different global scenarios showing that cropland expansion into forest and pasture may increase zoonotic hazards in areas with high rodent species diversity. All scenarios presented high heterogeneity in zoonotic hazard, with high-income countries having the lowest hazard range. Biodiversity conservation at the appropriate scales, protecting natural areas from human incursion and management of particular species or habitats should reduce spillover risk, thus biodiversity conservation and management need to be considered alongside other disease management options (Rohr *et al.*, 2020). Conservation measures can also reduce contamination of freshwater sources by zoonotic enteric pathogens, and so may help prevent projected increases in diarrhoeal disease from climate change (Chen *et al.*, 2022; Moors *et al.*, 2013).

Interacting effects of increasing land demand for food and biofuels and climate change are likely to increase cross-species transmission from wild animals to humans in the future (Carlson *et al.*, 2022). Deforestation and subsistence hunting for food from wild animals (bushmeat) will also increase the probability of future spillover events and emergence of novel diseases (Carlson *et al.*, 2022), while reforestation and urban greening, in particular, has enabled *Ixodes ricinus* to expand its distribution within Europe (Köhler *et al.*, 2023).

Overall, urbanization and wealth are associated with lower burdens for many diseases, a pattern that could arise from increased access to water and sanitation (Wood *et al.*, 2017). Conversely, accelerating urbanization, connectivity and climate change will enable the spread of chikungunya, dengue, Zika and Yellow Fever and other human mosquito-borne diseases in response to future projected distributions of partly invasive vector mosquitoes (Baker *et al.*, 2022; Kraemer *et al.*, 2019; Mora *et al.*, 2022). A multi-model multi-scenario intercomparison modelling study by (Colón-González *et al.*, 2021) assessing possible spatial shifts of these diseases due to climate change and urbanization in the future projected that approximately 700 million additional people in Africa, a similar number in South-East Asia, and 200 million in the Americas would be at risk of malaria and dengue by 2070 relative to 1970-99, particularly in lowlands and urban areas, without accounting for urban heat island effects. Projected people at risk might not translate into increased morbidity if health systems can identify and suppress infections.

Urban areas also provide microclimates that might enhance the development and survival of some mosquito species, such as *Anopheles stephensi* and Aedes mosquitoes (Mordecai *et al.*, 2020). Synergies between urbanization and warmer temperatures could increase the risk of urban malaria from *Anopheles stephensi* or promote a shift from malaria to dengue transmission (Colón-González *et al.*, 2021; Mordecai *et al.*, 2020). The epidemic belt for both diseases, malaria and dengue, is projected to expand towards temperate areas (Colón-González *et al.*, 2021). By simulating the combined effect of scenarios under a warming climate on precipitation, land cover, host availability and ongoing reproduction, Khan *et al.*, (2020) investigated future ecological niches of *Aedes albopictus* and *Aedes aegypti* mosquito species in North America. The investigation found that under RCP 4.5 and 8.5 emissions scenarios, the distribution of the two species (vector of more than 22 arborviruses) would expand to all coastal regions of the northwestern United States and the southern coastal border of Canada's Ontario province by 2100 compared to 2011. This is especially significant given the large numbers of people expected to be residing in those areas by this time period. Furthermore, the fact that *Aedes*-borne infections are not currently prevalent in the United States and Canada could mean potential inertia within the healthcare systems in promptly diagnosing and responding to any emerging vector-borne diseases (Ng *et al.*, 2019). This trend is the opposite to what was reported for tsetse flies, for which the terrestrial habitable area in Tanzania is projected by Nnko *et al.* (2021) to decrease by 23 per cent by 2050 under the RCP 4.5 scenario, with consequences for surveillance and control of human trypanosomiases transmission.

As for future scenarios of the impacts of zoonoses on other nexus elements, pathways of covid-19 post-pandemic recovery have shown that dietary transition towards less meat and more fruit and vegetables could prevent many excess deaths, increase the area of natural land (for biodiversity), reduce nitrogen fertilizer use, and reduce irrigation water usage for food production (Maire *et al.*, 2022). As such, the effects of the pandemic lockdown are a complex mixture of positive and negative impacts on nature, all of which have the potential to lead to cascading responses which in turn impact wildlife and nature conservation (Bates *et al.*, 2021). Health, food security and the environment benefit from more societally cooperative pandemic responses that result in reduced trade barriers and improved technological development (Maire *et al.*, 2022).

3.5.2.2 Marine realm

The links between health and ecological processes in the marine realm are mostly indirect, and consequently not considered frequently in future projections in a nexus context. In fact, most health outcomes are treated as 'co-benefits' of interventions in other nexus elements. Scenario-based assessments of marine/coastal ecosystem targeted interventions on health outcomes are therefore rare. Where they exist, they tend to posit health as mostly affected by water or food quality (i.e., through pollutants or disease; see **sections 3.4 and 3.5**, respectively) and climate change (see **section 3.6**). Land-use change in coastal environments can also impact health, for example, the loss of mangroves moves the forest frontier and its constituent fauna closer to human settlements. As described by Magouras *et al.*, (2020), such landcover shifts have the potential to increase human-animal interaction, thus increasing the risk of disease spillover and promoting emergence and spread of zoonosis.

3.5.3 Scenarios of health related to green and blue spaces

The Intergovernmental Panel on Climate Change has concluded that extreme events related to climate change will significantly increase ill health and premature deaths (IPCC, 2022a). In this respect, green spaces reduce urban heat islands, positively affect physical and mental health and provide adaptation to extreme heat (Romanello *et al.*, 2022).

Several studies have estimated future heat exposure related to climate scenarios, but few account for interactions with other nexus elements. Urban heat island effects were estimated to be responsible for about 4 per cent of heat-related deaths in 93 European cities in 2015 (Iungman *et al.*, 2023). While increasing urban tree coverage could theoretically result in a 0.4°C decrease in urban temperature and prevent about 40 per cent of heat-related deaths, it is not clear that this strategy would be as successful in practice under future climate change conditions. Vargo *et al.* (2016) estimated the effect of increasing urban green space on heat-related mortality in three US cities in 2050. Compared to BAU, small reductions of 5-10 deaths per million population per year were simulated in scenarios of increased green space. Using an urban climate model, Verdonck *et al.* (2019) compared future exposures to heat stress in the 2040s and 2090s in Brussels, Belgium, under two urban planning and two climate change scenarios (RCPs 4.5 and 8.5). They reported that the climate scenario was the most important factor determining projected heat stress, and that urban planning had relatively little effect. Urban green and blue can also affect the presence of vectors and hosts, as well as the human-animal interface, which may increase infectious disease risk. Hence, decision-support tools that track future climate-induced disease risks become increasingly important (Rocklöv *et al.*, 2023).

Hyytiainen *et al.* (2021) simulated two global futures of recreational opportunities stemming from non-material NCP provided by the aquatic ecosystems of the Baltic Sea. Their results indicate that recreational NCP increase significantly under RCP 4.5 scenario at the end of this century, whereas they decrease under the more extreme RCP 8.5 scenario. Loss of recreational opportunities are linked to proliferation of cyanobacteria due to a 96 per cent increase in primary production, thereby reducing aesthetic value and making these environments unsuitable for activities such as swimming. This trajectory has consequences for biodiversity arising from increased production of zooplankton, the main food source for pelagic fish that serve as food for cod. A further increase in organic matter sedimentation would increase benthic biomass in moderate amounts but destroy benthic fauna at more elevated levels *via* hypoxia inducement (Conley *et al.*, 2009; Ehrnsten *et al.*, 2019).

Yee *et al.* (2021) modelled the potential impacts of climate change scenarios under existing land-use on the ecosystem services of Pensacola Bay, Florida, United States and their effects on human well-being between 2010 to 2050. The authors found that under a B1 scenario, which emphasizes global solutions to economic, social and environmental sustainability (IPCC, 2000), counties within the bay with the fastest projected transitions from urban, barren pasture or agricultural land to forests would experience increasing health and well-being indicators over the 40-yr period. However, food, fibre and fuel plus the strongly linked leisure time indicator scores declined as raw materials and energy sources were used up, although at a slower rate than the A2 scenario, which assumes a fragmented world focused on self-reliance (IPCC, 2000). Conversely, declining forest cover under that scenario diminished the ability of the bay's ecosystems to provide green spaces, buffer air pollutants, retain rainwater and provide habitats for biodiversity.

3.6 CLIMATE-ORIENTED SCENARIOS AND THEIR NEXUS INTERACTIONS

This section synthesizes the scenario literature on climate change and its interactions with the other nexus elements, particularly with respect to climate action needed to meet the long-term global goals of the Paris Agreement. It is structured into three sections focusing on: (i) scenarios of climate change impacts; (ii) scenarios of climate change mitigation; and (iii) scenarios of climate change adaptation.

Many scenario studies have been undertaken on climate change impacts, adaptation and mitigation (IPCC, 2022a); out of the scenarios in the structured review, an assessment of potential future nexus interactions was included in 112 scenarios. Those studies predominantly relied on exploratory (rather than target-seeking) scenarios, about half were of global scope opposed to national or sub-national scope, and all were based on researcher-designed (rather than participatory) scenarios with no inclusion of ILK.

Climate change impacts, mitigation and adaptation actions are tightly intertwined with many dimensions of sustainable development (van Soest *et al.*, 2019) and biodiversity conservation (Arneth *et al.*, 2020; IPCC, 2022a; Pörtner *et al.*, 2023; P. Smith *et al.*, 2022) and, hence, with the other nexus elements. It is likely that exposure to multi-sector risks (such as in the energy, transport and land-use sectors) will double under the 1.5°C and 2°C climate goals relative to pre-industrial levels, and double again in a 2°C to 3°C world (Byers *et al.*, 2018; IPCC, 2022a), with delayed actions increasing long-term cost to the economy and human society substantially (Bertram *et al.*, 2018; Hoegh-Guldberg *et al.*, 2018; Zhao *et al.*, 2020).

3.6.1 Impacts of multiple drivers on climate change

Changes in agriculture, forestry and other land-uses are a major driver of climate change (Hoegh-Guldberg *et al.*, 2019; IPCC, 2022a), but can also contribute to mitigation efforts if well managed (Roe *et al.*, 2019). The demand for land as a driver of deforestation is expected to further amplify climatic extremes and variability (Alkama & Cescatti, 2016), while also causing biodiversity decline. Feedbacks between climatic extremes and deforestation caused by food demand could potentially turn the Amazon rainforest from a carbon sink to a carbon source (Parry *et al.*, 2022). Similar tipping points across the world indicate the strong interlinkages among drivers of climate change (Armstrong McKay *et al.*, 2022).

Impacts of climate change across the nexus elements are projected to accelerate with both average warming and extreme climatic events (IPCC, 2022a). This can result in increasingly complex and coupled risks such as repeated droughts and resulting yield losses and land-use change (Ivanovich *et al.*, 2023; Zaveri *et al.*, 2020), which in turn affect GHG emissions (Lamb *et al.*, 2021). In the marine realm, fish harvests and unsustainable fishing practices also contribute to climate change (Bianchi *et al.*, 2021; Mariani *et al.*, 2020; Siegel *et al.*, 2023), with ocean fisheries having reduced biological carbon storage by about 10 per cent (Bianchi *et al.*, 2021).

Addressing the drivers of climate change supports the achievement of other policies, such as the SDGs across the whole nexus (Scharlemann *et al.*, 2020). For example, out of the 21 targets of the Kunming-Montreal Global Biodiversity Framework aimed at addressing the causes of biodiversity loss, 14 generally have direct positive synergies with climate change mitigation and adaptation (Shin *et al.*, 2022), highlighting the commonalities in underlying drivers (Pörtner *et al.*, 2021a, 2023). Thus, addressing the causes of climate change through mitigation or adaptation necessarily means considering other nexus elements.

3.6.2 Scenarios focused on climate change impacts

3.6.2.1 Terrestrial realm

Climate change is known to impact all nexus elements and their interactions across various future scenarios (IPCC, 2022a; Pörtner *et al.*, 2021b). Direct impacts are well known and documented, such as for biodiversity (Beaumont *et al.*, 2011; Begum *et al.*, 2022), water (Schewe *et al.*, 2014), food (S. Frank *et al.*, 2014; Fujimori *et al.*, 2019) and health (K. Smith *et al.*, 2014). In addition, climate change can affect the nexus elements indirectly such as through the economy *via* impacts on food prices and trade (Hoegh-Guldberg *et al.*, 2019; van Meijl *et al.*, 2018). While the impacts on individual nexus elements are well understood (IPCC, 2022b, 2022a), impacts on interactions among nexus elements are less so (IPCC, 2021).

Realised impacts from climate change will differ with the level of transformative ambition, i.e., limiting global warming to 1.5°C or 2°C, as well as the amount of climate mitigation and adaptation efforts (IPCC, 2022b). However, some climate change impacts also have positive interactions with other nexus elements albeit with considerable uncertainty (P. A. Harrison *et al.*, 2016). For example, a rise in concentration of GHGs such as CO_2 is projected to facilitate plant growth and increase crop yields, with benefits likely depending on land-use practices and water use efficiency (Jägermeyr *et al.*, 2021; Krause *et al.*, 2019). As agro-climatic zones shift northwards in response to climate change (Ceglar *et al.*, 2019), changes in the composition of crop production in the global north will likely cause further negative impacts on water supply, soils and natural habitats (Hannah, Roehrdanz, Krishna Bahadur, *et al.*, 2020).

3.6.2.2 Marine realm

Projections of impacts of climate change on marine ecosystems have revealed long-term global declines in marine animal biomass, expected to be most severe under the worst climate scenario, and which are associated with trophic amplification and changes in fisheries (Boyce *et al.*, 2020; Bryndum-Buchholz *et al.*, 2020; Burgess *et al.*, 2023; Coll *et al.*, 2020; Lotze *et al.*, 2019; Tittensor *et al.*, 2021). However, regional shifts are more uncertain, with highest uncertainty in the Arctic and lowest in the south Pacific (Bryndum-Buchholz *et al.*, 2020; Lotze *et al.*, 2019; Tittensor *et al.*, 2021) **(Box 3.7)**. Additionally, climate change is projected to affect distributions of commercially important fishes. For example, (Kleisner *et al.*, 2017) projected that suitable habitat for southern distributed fishes in the northeast continental shelf of the United States would be stable or increase by 2060-2080, but decrease for species with northern distributions. However, when salinity and sea surface height were included in the climate change projections, a significant change in range was projected for southern species as well, with an overall 53 per cent of species experiencing a decline and a total reduction in suitable area of 3,000 km^2 (McHenry *et al.*, 2019). Such changes in fish distributions are likely to affect the type of fish caught for consumption, although new opportunities may arise through changes in target fisheries (Kleisner *et al.*, 2017). Increases in richness of

Box 3 7 **Marine scenario planning under climate change in the Kitikmeot region in Nunavut, Canada.**

Knowledge co-production is a collaborative process that draws from multiple knowledge systems and methodologies to address a specific problem. One tool for collaboration is participatory scenario planning, a place-based approach which brings together different knowledge holders to mobilize knowledge and address a particular topic. Such an approach was deployed in the Kitikmeot region in Nunavut, Canada, to explore future scenarios with positive outcomes (Falardeau *et al.*, 2019). The region has ~6,500 inhabitants, 90 per cent of which are Inuit and 50 per cent are under 25 years old.

Scenarios explored a predetermined set of different trends of marine development, governance and climate change by 2050. They were cocreated in workshops with participants from the Inuit community, managers and scientists using a process that bridged local and scientific knowledge (Falardeau *et al.*, 2019). The process involved five steps (Falardeau *et al.*, 2019). First, elders described the important values of the communities and the aspects of the marine environment they hoped would persist in the future. Second, plausible scenarios were grouped around two axes of uncertainty, associated with seascape development and governance. Third, Arctic *seeds*, defined as initiatives or organizations that are making positive changes for the benefit of people and the environment, were used to develop scenario boundaries. Fourth, art was used to flesh out narratives of the different scenarios, recognizing its importance in bridging knowledge systems. And fifth, different pathways that achieve the positive visions for the future were discussed.

The three scenarios varied in governance control (local communities *versus* federal government) and types of development (tourism, fisheries and traditional activities *versus* shipping and mining) under the potential impacts of climate change (reduction of ice extent, delay in ice forming). The scenarios explored potential impacts on the environment and people (e.g., ocean pollution, health of the marine web, Arctic char, new species in the ocean, polar bears, fisheries, hunting, and art and storytelling) (Falardeau *et al.*, 2019).

Overall, although many challenges are associated with future development under climate change, opportunities also exist and the actors in local government play a critical role in mitigating impacts. For example, in a scenario with local government control and a development focus on fisheries, tourism and traditional activities, populations of seals, whales, polar bears and Arctic char are expected to decrease, and ocean pollution to increase. However, revenue and jobs, art and storytelling, community wellness and social relations, and spirituality are expected to increase by 2050. In a scenario with federal government control and a development focus on shipping and mining, although many aspects will worsen (e.g., increase in ocean pollution, decreases in Arctic char and marine fishes, decrease in the health of the marine food web, and loss of Inuit culture and identity), some other aspects will improve (e.g., increases in fisheries, art and storytelling and spirituality).

The findings can be used to identify concrete actions to reach the positive outcomes and mitigate the identified challenges. Examples of such actions include assuring local governance and developing strict regulations, ecological monitoring and increasing education of young Inuit in Indigenous and local knowledge. This includes empowering and equipping them to assume influential roles in shaping the future of their region.

fisheries species have been projected in the poles with a concomitant decrease at the equator by 2040-2059 (M. C. Jones & Cheung, 2015). Specifically, 93-95 per cent of species shifted northward (at an average of 15.5-25.6 km per decade, depending on climate scenario) (M. C. Jones & Cheung, 2015).

Outcomes vary regionally and the severity of impacts is correlated with socio-economic factors, such as GDP and economic adaptive capacity (Boyce *et al.*, 2020; Bryndum-Buchholz *et al.*, 2020; Coll *et al.*, 2020; Sala *et al.*, 2021). For example, climate vulnerability and risk (including to fisheries) increase for higher emission scenarios but can be geographically disproportionate in coastal tropical regions with higher diet shares of marine fish (Boyce *et al.*, 2022). Climate-driven biomass changes will widen existing equity gaps and disproportionally affect populations that contributed least to global GHG emissions (Boyce *et al.*, 2020). For example, in the Arctic, ice retreat will have a significant impact on the social structure of Indigenous communities by opening up to greater development of industrial activities, such as shipping and oil and gas exploration, which may increase income, but may also disrupt subsistence activities, such as fishing and hunting, and increase pollution (Cochran *et al.*, 2013) **(Box 3.7)**.

3.6.3 Scenarios focused on climate change mitigation

Climate change mitigation is crucial as it can reduce individual and compound risks for most nexus elements. Mitigation measures, on the production as well as on the consumption side, can be used to either reduce GHG emissions or enhance carbon sequestration.

3.6.3.1 Terrestrial realm

Without effective land-based mitigation the long-term global goals of the Paris Agreement will not be met, as global food production alone could push the climate system beyond the 1.5°C target (Clark *et al.*, 2020; Lee *et al.*, 2019). These include actions for either decreasing land-related GHG emissions, bioenergy carbon capture and storage (BECCS) or enhancing land-related carbon stocks. At the same time, climate change mitigation action – if not well managed and implemented – has the potential to impact other nexus elements in harmful ways. Thus, when considering goals for averting the most severe climate change impacts, synergies between mitigation actions and other nexus elements should be sought, with integrated actions likely to provide the greatest benefits (Pörtner *et al.*, 2021b).

Many climate change mitigation measures often have synergies and trade-offs with other nexus elements. For example, measures such as reforestation, protection of carbon rich ecosystems and restoration of wetlands provide co-benefits for biodiversity. For example, there are estimates that afforestation on abandoned cropland can mitigate up to 2 to 11 per cent of global CO_2 emissions while bringing co-benefits to biodiversity (Gvein *et al.*, 2023), despite being less efficient than BECCS on the same land. In contrast, measures, especially those enhancing competition for resources such as land or water (e.g., bioenergy from dedicated crops, afforestation), may be detrimental if applied at a large scale and not well-managed locally (e.g., *via* protection of biodiversity-rich ecosystems) (Merfort *et al.*, 2023). For instance, there are synergies between increased energy efficiency as a climate change mitigation measure and future reductions in air pollution, with substantial health co-benefits (Bertram *et al.*, 2018; Hamilton *et al.*, 2021; Zhang *et al.*, 2021). Other climate change mitigation measures that target higher carbon prices may reduce cropland requirements for food and thus exert pressure on nature (Bertram *et al.*, 2018), although this comes with higher, short-term economic costs.

Relying on one mitigation measure only (such as second-generation bioenergy production) in the land-sector could generate trade-offs with biodiversity and food (Prudhomme *et al.*, 2020), highlighting the importance of future competition for land. Portfolios of mitigation measures such as a combination of second-generation bioenergy production, dietary change and reforestation of pasture are needed to minimize trade-offs between biodiversity and food (Prudhomme *et al.*, 2020). Novel approaches to bioenergy such as microalgal production systems are a promising alternative with potentially fewer environmental impacts (Correa *et al.*, 2017). Microalgal systems may generate fewer pressures on biodiversity per unit of fuel generated in the future, compared to first generation biofuels, mainly because of reductions in direct and indirect land-use change, water consumption if water is recycled and no application of pesticides. However, further improvements in technologies and production methods are still required (Correa *et al.*, 2017).

Key climate change mitigation options include energy supply from renewable energy sources such as wind, solar and hydropower, given that energy demand is expected to increase significantly over the coming decades (IEA, 2019; Saah *et al.*, 2014). Future energy demand from local to global scale can be secured through a diversified energy mix, all of which may lead to different implications for the interactions between nexus elements.

Harvesting of fuelwood for bioenergy purposes may increase in importance in the future, with potentially large effects on other nexus elements, e.g., on water chemistry, biodiversity, soil properties and long-term productivity. In this respect, studies have assessed thresholds for sustainable harvesting volumes in the future (de Jong *et al.*, 2017). For example, planting forests to supply fuelwood and biofuels (e.g., in the form of forest plantations) may increase the risk of nutrient removal and nitrogen limitation problems, with subsequent impacts on forest species diversity (Forsius *et al.*, 2016). In some cases, clear trade-offs may be observed between maximizing the use of energy-wood and minimizing impacts on species diversity, soil carbon and nutrient stores and nutrient leaching (Forsius *et al.*, 2016).

Climate change mitigation measures that target several nexus elements might limit exposure to multiple climate-induced risks (Byers *et al.*, 2018; Skoulikaris *et al.*, 2021). Measures that target multiple sectors in parallel, particular in the context of the SDGs, have the potential for order-of-magnitude scale reductions in multi-sector climate change impacts for the most vulnerable (Bertram *et al.*, 2018; Byers *et al.*, 2018; Fujimori *et al.*, 2020). Such cross-sectoral thinking with a portfolio of measures across mitigation pathways could provide synergistic effects across the nexus, for example, through a combination of climate change mitigation measures including an improvement in energy efficiency, nuclear phaseout and substantial lifestyle changes (Bertram *et al.*, 2018). Similarly, the implementation of carbon dioxide removal (CDR) approaches, such as enhanced weathering, direct air capture or biochar among others, are often a critical feature within many future scenarios that explore how the climate goal of 1.5°C can be reached (IPCC, 2022b). Combining a diverse set of CDR approaches across terrestrial ecosystems and oceans, including direct air capture, can reduce impacts and economic costs of their employment across the nexus (Fuhrman *et al.*, 2023).

Another critical dimension is the time frame of action for mitigation as windows for interventions close. Earlier mitigation measures, while more economically costly in the short-term, are cost-efficient in the long-term with overall reduced future economic impacts and fewer trade-offs with other nexus elements (Bertram *et al.*, 2018; Lee *et al.*, 2019). Regardless of the climate goals, delaying sufficient climate change mitigation actions proves costlier in the long-term, but also exhibits larger uncertainties with regards to complex dynamics and feedbacks across the nexus (Koven *et al.*, 2022). For example, the combined impact of climate and land-use change may increase the risk of humans being exposed to zoonotic diseases and cross-species viral exchanges with wild animals (Carlson *et al.*, 2022), yet only a limited reduction in risk is to be expected with climate change mitigation efforts as many species shift their geographic distribution. Within a 1.5°C or 2°C climate goal there is a tendency for economic damages on ecosystems to flatten as mitigation measures become more efficient (Zhao *et al.*, 2020). Overall, this highlights the need for dedicated response options that consider multiple elements of the nexus.

Table 3.3 shows illustrative climate action pathways for achieving climate targets with varying levels of ambition and interaction with other nexus elements. BAU pathways without climate change mitigation strategies could lead to unabated global warming to +2.8°C or more with detrimental consequences for all nexus elements (Jägermeyr *et al.*, 2021; Kelman *et al.*, 2021; Thompson *et al.*, 2021). Delayed action (DEL) pathways differ strongly in terms of the mitigation target (limit warming to 2°C) and focus on the supply side of mitigation measures. Delayed emission reductions in all sectors, especially the energy sector, increase the need for large-scale, land-based carbon dioxide (CO_2) removal (Luderer *et al.*, 2022; Strefler *et al.*, 2018). As a consequence, competition for land and water increases (Fuhrman *et al.*, 2020) and much more other natural land as well as agricultural land (cropland and pasture land) is converted to forest or bioenergy cropland with potentially severe consequences for various nexus elements such as biodiversity (Hof *et al.*, 2018), water use for bioenergy crops (Bonsch *et al.*, 2016) and food security (Fujimori *et al.*, 2019). Sustainable development (SDP) pathways, such as those assumed under SSP1, display a future of generally low resource and energy consumption (including sustainable healthy diets with low animal-calorie shares and low food waste), significant but sustainable agricultural intensification in combination with high levels of nature protection and early GHG mitigation efforts in other sectors (Soergel *et al.*, 2021). As a result, comparably small amounts of land are needed for land-demanding mitigation activities such as bioenergy and afforestation. In particular, the amount of agricultural land converted to bioenergy cropland as well as water required for irrigation are lower compared to the DEL mitigation pathway. This has beneficial effects for ecosystem and biodiversity protection and regeneration, water quantity as less water is used for irrigation, water quality due to less intensified agriculture and associated pollution (with e.g., nitrogen), food production due to lower food prices associated with lower competition for land, water and other inputs as well as health due to more sustainable healthy diets with less under and overnutrition.

Table 3.3 **Illustrative climate action pathways.**

Pathways for achieving climate targets based on diverging general strategies, highlighting underlying climate change mitigation strategies as well as the interaction with other nexus elements. Colour codes relate to desirability of outcomes: green being the most desirable, orange the least desirable with yellow in between.

Climate action pathway	Climate change	Biodiversity	Water	Food	Health
Business-as-usual (BAU)	No climate action beyond current policies, or even less climate action				
	Unabated global warming to +2.8°C or more, with risk of reinforcing effects from biodiversity degradation	Decreasing global biodiversity trends from habitat conversion, overexploitation, etc. and accelerated in the second half of the century by unabated climate change	Mostly negative impact as water is affected by climate change, increasing scarcity and pollution	Negative impacts from climate change increasing in the long run with potential short-term benefits in some regions; food security risks potentially reduced by increased food production in the short run but also affected by other factors	Projected negative impacts from extreme climate events on health (e.g., heatwaves), plus indirect negative effects on nutrition, infectious diseases and mental health. Potential health co-benefits of climate change mitigation not realised

Table 3 3

Climate action pathway	Climate change	Biodiversity	Water	Food	Health
Delayed Action (DEL)	Increased climate action ambition but starting late, not including demand / lifestyle changes measures, and not considering potential adverse effects on other nexus elements. Due to delayed action and limited reliance on demand measures and lifestyle changes, pressures on land and water resources increase (i.e., higher negative emissions are required and food / energy consumption remain high). Mitigation measures are not designed in an integrated fashion and entail missed opportunities (e.g., weak protection of ecosystems) and large risks to other nexus elements (e.g., large development of biofuels). Chances to reach climate mitigation well below 2°C are limited.				
	Limited global warming to +2°C	Risk of trade-offs from large reliance on biodiversity-unfriendly climate action (large afforestation and biofuels) and negative impacts from residual climate change	Risk of trade-offs from large reliance of water-unfriendly climate action (large afforestation and biofuels) and negative impacts from residual climate change	Potentially larger negative impacts from mitigation impact than avoided climate change	Most of the above-mentioned negative impacts remain, apart from avoided climate change impacts
Sustainable Development Pathway (SDP)	Increased climate action ambition starting rapidly, including demand / lifestyle changes measures and explicitly considering potential adverse / synergistic effects on other nexus elements. Due to early action and reliance on demand measures and lifestyle changes, pressures on land and water resources decrease (i.e., a limited amount of negative emissions are required and food / energy consumption decrease to more sustainable levels). Mitigation measures are designed in an integrated fashion and entail mobilization of synergistic options (e.g., strong protection of ecosystems) and avoidance of solutions detrimental to other nexus elements. A high level of coordination across spatial scales is achieved, allowing solutions to be tailored to local contexts. Chances to reach climate change mitigation well below 2°C are increased.				
	Limited global warming well below +2°C	Positive synergistic effects from reduced pressure from unsustainable consumption, climate action prioritizing ecosystem protection and restoration, limited negative impacts from residual climate change	Positive synergistic effects from reduced pressure from unsustainable consumption, climate action avoiding increased pressure (but some trade-offs associated energy transition might remain), limited negative impacts from residual climate change	Positive synergistic effects from reduced pressure from unsustainable consumption and sustainable healthy diets, avoided climate change impacts	Positive synergistic effects from reduced climate extremes, effective adaptation measures, improved food and water security, avoided infectious and non-communicable diseases. Health co-benefits of mitigation policies (reduced non communicable disease attributable to improvements in diet, physical exercise and air pollution)

3.6.3.2 Marine realm

The ocean can play a key role as a mitigator of climate change in the future. For example, seaweed aquaculture could help mitigate climate change, in addition to providing a source of food (Duarte *et al.*, 2022). While the role of seaweed in climate change mitigation and carbon sequestration is still considered to be uncertain (Ross *et al.*, 2023), studies show that by releasing dissolved and particulate organic carbon which eventually becomes buried in marine sediments, farmed seaweed could sequester about 421 Tg CO_2 yr−1 in coastal sediments globally by 2050 at maximum farming growth potential (Duarte *et al.*, 2022). Offshore afforestation of seaweed has also been proposed as a strategy for marine carbon dioxide removal (Duarte *et al.*, 2017; N'Yeurt *et al.*, 2012), although the impacts of large-scale offshore farming and eventual sinking and burying of seaweed are currently unknown (Boyd *et al.*, 2022). In the nutrient-limited open ocean, afforestation may lead to ever diminishing supplies of nutrients and consequent changes in the size distribution and flux of organic particles (and thus the quantity and quality of food supply) to the deep sea (Levin *et al.*, 2023). Changes in carbon cycling on and in the seabed by potential changes in the dominant functional animal groups could disturb the existing carbon reservoir in the marine sediments (DeAngelo *et al.*, 2023a, 2023b).

3.6.4 Scenarios focused on climate change adaptation

Although climate change mitigation remains the most cost-efficient and just way to prevent the most extreme climate change impacts, the actual severity of impacts will vary with the amount of implemented climate change adaptation measures (IPCC, 2022a; Werners *et al.*, 2021).

3.6.4.1 Terrestrial realm

Increasing human population and thereby food and biofuel demand requires agricultural expansion, dietary change and/or production gains from current land and water resources (Bahar *et al.*, 2020; Fitton *et al.*, 2019), the balance of which will affect future impacts on all nexus elements. Most scenarios that project transformative changes in response to climate change, such as increases in production efficiency and changes in fertilizer use (Alexander *et al.*, 2019; Folberth *et al.*, 2024; Jägermeyr *et al.*, 2021), contribute to climate adaptation by improving food system resilience and freeing up land for other nature-based solutions (NBS) such as conservation and restoration actions (Arneth *et al.*, 2021; Seddon, 2022; Seddon *et al.*, 2021). Similarly, scenarios of large-scale reforestation and ecosystem restoration can contribute to climate change adaptation, mitigation and biodiversity goals (Strassburg *et al.*, 2020) and reduce climate risks of extreme events such as flooding (Menéndez *et al.*, 2020). However, ecosystem restoration actions can also lead to trade-offs with pastoral food production, soil organic carbon retention or grassland-associated biodiversity, if trees are established on unsuitable land (Chausson *et al.*, 2020; Veldman *et al.*, 2019), or intensive food production is displaced into other regions or countries, with knock-on environmental impacts on natural habitats and biodiversity (Sloat *et al.*, 2020; Staccione *et al.*, 2023) and human health (Henry *et al.*, 2022).

There is good evidence that NBS (Pörtner *et al.*, 2023; Seddon, 2022) can reduce adverse climate change impacts, while improving social and biodiversity outcomes and adapting to a changing climate (Chausson *et al.*, 2020). Villarreal-Rosas found that integrating NBS in strategic planning has the potential to capture and restore up to 89 per cent of carbon rich ecosystems, increase environmental flows, while allowing maintenance cost reductions for hydropower (Villarreal- Rosas *et al.*, 2023). Spatial planning that takes projected distributions of species and climate risks into account, could contribute to overall more resilient and effective protected area network (Jung, Alagador, *et al.*, 2023). Momblanch *et al.* (2022) demonstrated that an ecologically oriented reservoir management adaptation scenario increased the likelihood of persistence of the rare Indus River Dolphin, but negatively impacted energy production and urban water supply. Papadimitriou *et al.* (2019) also found potential unintended consequences for selected sustainable development indicators from all but one adaptation strategies, including sustainable water management, within the biodiversity-water-food nexus. In urban environments, adaptation strategies involving blue-green infrastructure have been found to deliver multiple benefits, including cooling *via* evapotranspiration, discharge peak attenuation, seasonal water storage and enhanced groundwater recharge (Voskamp & Van De Ven, 2015) and support biodiversity through improved landscape habitat connectivity (Donati *et al.*, 2022; Jung, Alagador, *et al.*, 2023).

3.6.4.2 Marine realm

Marine adaptation strategies include the development of climate-resilient aquaculture systems, sustainable fisheries management and ecosystem-based adaptation measures (Arkema *et al.*, 2017). For example, scenarios of marine climate change adaptation involve identifying and establishing resilient MPAs, including climate refugia (Pennino *et al.*, 2020), implementing adaptive management strategies and integrating climate change into conservation planning and decision-making (Bryndum-Buchholz *et al.*, 2023). Scenarios of marine climate change adaptation consider the vulnerability of coastal communities, incorporating traditional knowledge, promoting sustainable livelihoods and enhancing governance mechanisms for effective adaptation (Hare *et al.*, 2016; Ojea *et al.*, 2020).

Knowledge systems and practices of Indigenous Peoples are recognised as a key resource for climate change adaptation (IPCC, 2014, 2023; Petzold *et al.*, 2020; Schlingmann *et al.*, 2021) **(Box 3.8)**. The types of these adaptations vary with Indigenous and local knowledge systems, such as local plants for flood protection and technologies to improve water use (Paul & Routray, 2010). For example in Australia, traditional owners in the Great Barrier Reef area indicated that the best approach to climate change adaptation is through the protection of remaining Indigenous culture, narratives and relationships, linking the goals of climate change adaptation and cultural renewal (Lyons *et al.*, 2020). This approach supports decolonization and strengthens Indigenous customary practices and governance, thereby supporting strategies for cultural renewal and survival. In the African Sahel, local populations have developed and implemented adaptation strategies over long-time scales to reduce their vulnerability to climate change (e.g., early weather and climate warning systems, livestock management, seasonal mobility), which can add value when considered in formal climate change adaptation and mitigation strategies (Nyong *et al.*, 2007).

Box 3 8 **Indigenous climate change adaptation strategies.**

Adaptation to a changing environment has happened for as long as humans have been around. In relation to climate change, IPLC have developed and implemented a wide range of adaptation strategies (Hosen *et al.*, 2020; D. E. Johnson *et al.*, 2022; Nyong *et al.*, 2007), but these are often unreported (Schlingmann *et al.*, 2021). A recent review collated over 1800 cases of IPLC adaptation approaches to climate change, from across the world (Petzold *et al.*, 2020; Schlingmann *et al.*, 2021). These responses were classified into cultivation practices, livestock-related responses, fisheries-related responses and a cluster of other responses. The responses found were a combination of science-based and ILK-based responses (e.g., seasonal climate forecasting and Indigenous farming practices) (Cochran *et al.*, 2013).

While many responses involve changes to natural resource-based livelihoods, responses also involve other activities (e.g., networking, off-farm work). Petzold *et al.* (2021) report that the strongest forms of adaptation for IPLC represented in the literature were practices and behavioural measures, followed by planning and management. Globally, local responses to climate change impacts are more likely to be shaped by people's livelihood than by the climate zone where they live (Schlingmann *et al.*, 2021). This is an important consideration when adaptation options are considered, as most of the livelihoods are tied to local environments and how groups have co-evolved with those environments.

These examples illustrate that foresight and futures thinking arenas have not represented spaces of deliberation for ILK-based adaptation strategies, despite the evidence of the strategies employed. The function of these arenas cannot be fulfilled without ensuring that the interests of the concerned groups are adequately addressed. Consequently, a critical component of developing these arenas involves decolonizing the ways we think about the future by emancipating futures thinking from the frameworks that cannot adequately capture ILK framings of the future and creating new space for ILK paradigms (Lyons *et al.*, 2020; Maraud & Roturier, 2023).

3.7 SYNTHESIS AND DISCUSSION

The overarching goal of this chapter was to assess how the nexus elements and their interdependencies may change in the future, and what pathways and scenarios could lead to sustainable futures in which the nexus elements are managed and governed synergistically with minimal trade-offs.

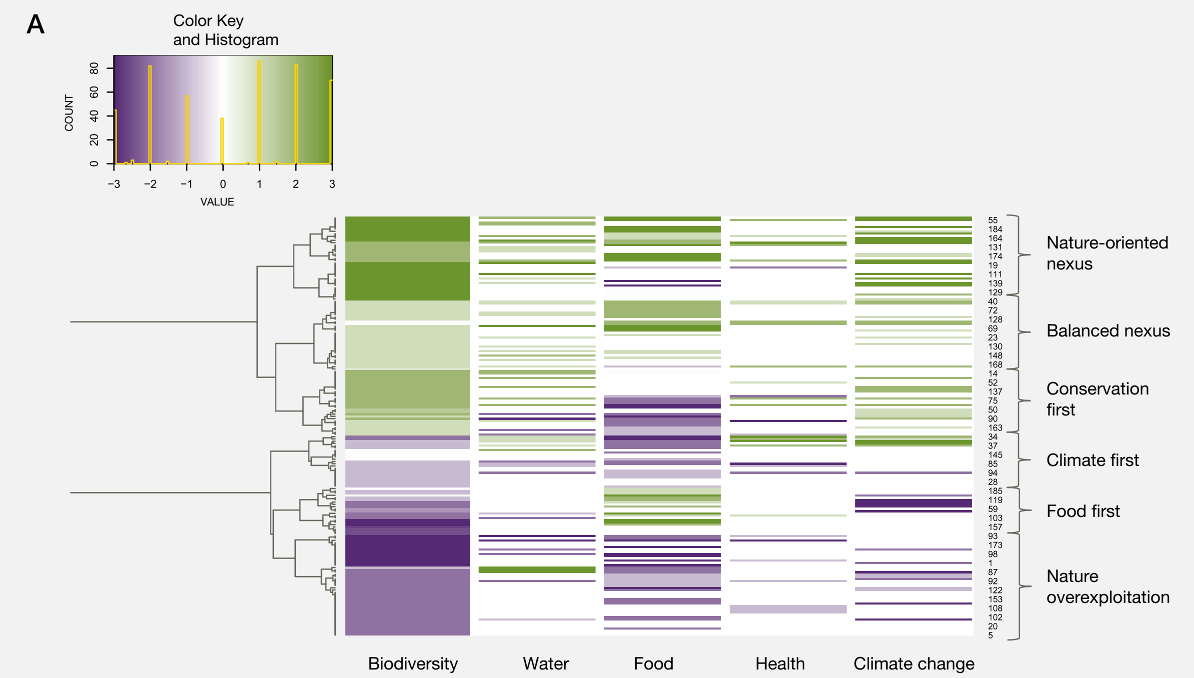
3.7.1 Synthesis across the nexus elements

This section synthesizes across the scenario outcomes with respect to the five nexus elements, the interactions between them, and the key characteristics of the scenarios which underline how the nexus elements interact. The analysis was informed by the 186 assessed scenarios that cover interactions between at least three nexus elements (see **section 3.1**). The scenarios primarily focus on the period 2050 and 2100. Approximately 60 per cent of the assessed scenarios address the role of indirect drivers. Around 88 per cent of the scenarios were quantitative, while 12 per cent were qualitative. Approximately 12 per cent of the scenarios were based on stakeholder engagement, with only 8 per cent including ILK systems, while about 88 per cent were designed by researchers without stakeholder input.

The synthesised sample of 186 scenarios included a number of BAU scenarios, which assume current trends will continue in the future and which covered different combinations of nexus elements **(sections 3.2.1, 3.3.1, 3.4.1, 3.5.1 and 3.6.1)**. These show increasing risks across most or all nexus elements and different NCP. They also show that climate change becomes a growing challenge to all nexus elements, including to ecosystem integrity and functioning. BAU scenarios also project water demand, mostly related to agricultural irrigation, to increase by 20-30 per cent in the 2050s compared to the 2010s. This increase may further undermine water quality, ecosystem health, and biodiversity habitats. In addition, these scenarios also include increasing food demand, including meat, and increasing food waste. In these scenarios, failures to meet food demand result in negative trends in all nexus elements, including nutritional health, due to inadequate nutrient supply linked to chronic diseases and premature mortality. Where they assume sufficient food supply, BAU scenarios include expansion and intensification of cropland and pasture. These are in turn associated with detrimental impacts on biodiversity caused by habitat conversion and overexploitation, feedbacks with global climate change, increasing water withdrawal and pollution. Limited quantitative estimates of health impact are available for BAU scenarios. However, climate change is projected to have net negative effects on malnutrition, heat-related human mortality and morbidity, food-borne, water-borne and vector-borne diseases, and mental health challenges.

The 186 assessed scenarios were clustered into six archetypical groups of scenarios referred to as "nexus scenario archetypes" **(Figure 3.6A)**. These were derived from an analysis of the outcomes of interactions between the nexus elements in terms of the direction (positive or negative) and magnitude (seven-point scale) of each interaction and the ensuing impacts on each nexus element. The six nexus scenario archetypes are: (1) *nature-oriented nexus,* (2) *balanced nexus*, (3) *conservation first*, (4) *climate first*, (5) *food first* and (6) *nature overexploitation* (**Figures 3.6**, **3.7** and **3.8**, **Table 3.4**). Overall, the scenarios assessed included a mixture of broadly positive *(nature-oriented nexus* and *balanced nexus)* and broadly negative *(nature overexploitation)* nexus interactions, with the remaining archetypes showing substantial trade-offs between nexus elements *(conservation first, climate first* and *food first)*.

Figure 3.6B summarizes the average impact of scenarios in each archetype on all nexus elements. These impacts result from the interactions between nexus elements **(Figure 3.6)** as well as the influence of direct and indirect drivers together with the implementation of response options. While *nature-*



B PROJECTED FUTURE IMPACTS ON THE NEXUS ELEMENTS

Nexus archetype	Nexus element: Biodiversity	Water	Food	Health	Climate
1. Nature-oriented nexus	Highly positive	Moderately positive	Slightly positive	Slightly positive	Moderately positive
2. Balanced nexus	Slightly positive	Slightly positive	Moderately positive	Moderately positive	Slightly positive
3. Conservation first	Moderately positive	Variable	Moderately negative	Variable	Slightly positive
4. Climate first	Slightly negative	Variable	Moderately negative	Slightly positive	Moderately positive
5. Food first	Moderately negative	Slightly negative	Moderately positive	Slightly positive	Moderately negative
6. Nature overexploitation	Moderately negative	Variable	Moderately negative	Slightly negative	Moderately negative

Impacts on each nexus element under each nexus archetype: Highly positive; Moderately positive; Slightly positive; Variable; Slightly negative; Moderately negative; Highly negative

Figure 3.6 **Nexus scenario archetypes and future impacts on the nexus elements.**

(A) Nexus scenario archetypes: six clusters of nexus interactions as represented in 186 scenarios. From top to bottom, the interactions go from broadly positive (for *nature-oriented nexus, balanced nexus and conservation first*), to broadly negative (for *climate first, food first and nature overexploitation*). Blank (white) bars indicate that there were no data for that nexus element within the scenarios analysed. **(B)** Projected future impacts on the nexus elements: average magnitude of impact of each nexus scenario archetype on each nexus element.

oriented nexus and *balanced nexus* are characterized by strong and moderately strong, positively reinforcing interactions (e.g., sustainable healthy diets supporting both biodiversity protection and climate change mitigation), *conservation first, climate first* and *food first* show a combination of positive and negative interactions between nexus elements. The broadly negative nexus scenario archetype – *nature overexploitation* – is characterized by moderately to highly strong negative interactions between elements, e.g., water pollution and crop monocultures exacerbating biodiversity loss (see **Table 3.4** for further examples).

Scenarios in the *nature-oriented nexus* and *balanced nexus* archetypes with positive outcomes across the nexus elements are characterized by flexible and well-functioning institutions. This includes mainstreaming and enforcing environmental and pro-sustainability regulations and facilitating cooperation between countries and societal sectors such as governments, non-governmental organizations and businesses (B. Bauer *et al.*, 2019; Bertram *et al.*, 2018; Moallemi *et al.*, 2022; Tallis *et al.*, 2018; Wöhler *et al.*, 2020) **(Figure 3.8)**. They also tend to include participatory and inclusive decision-making, and knowledge-sharing across actors (Falardeau *et al.*, 2019;

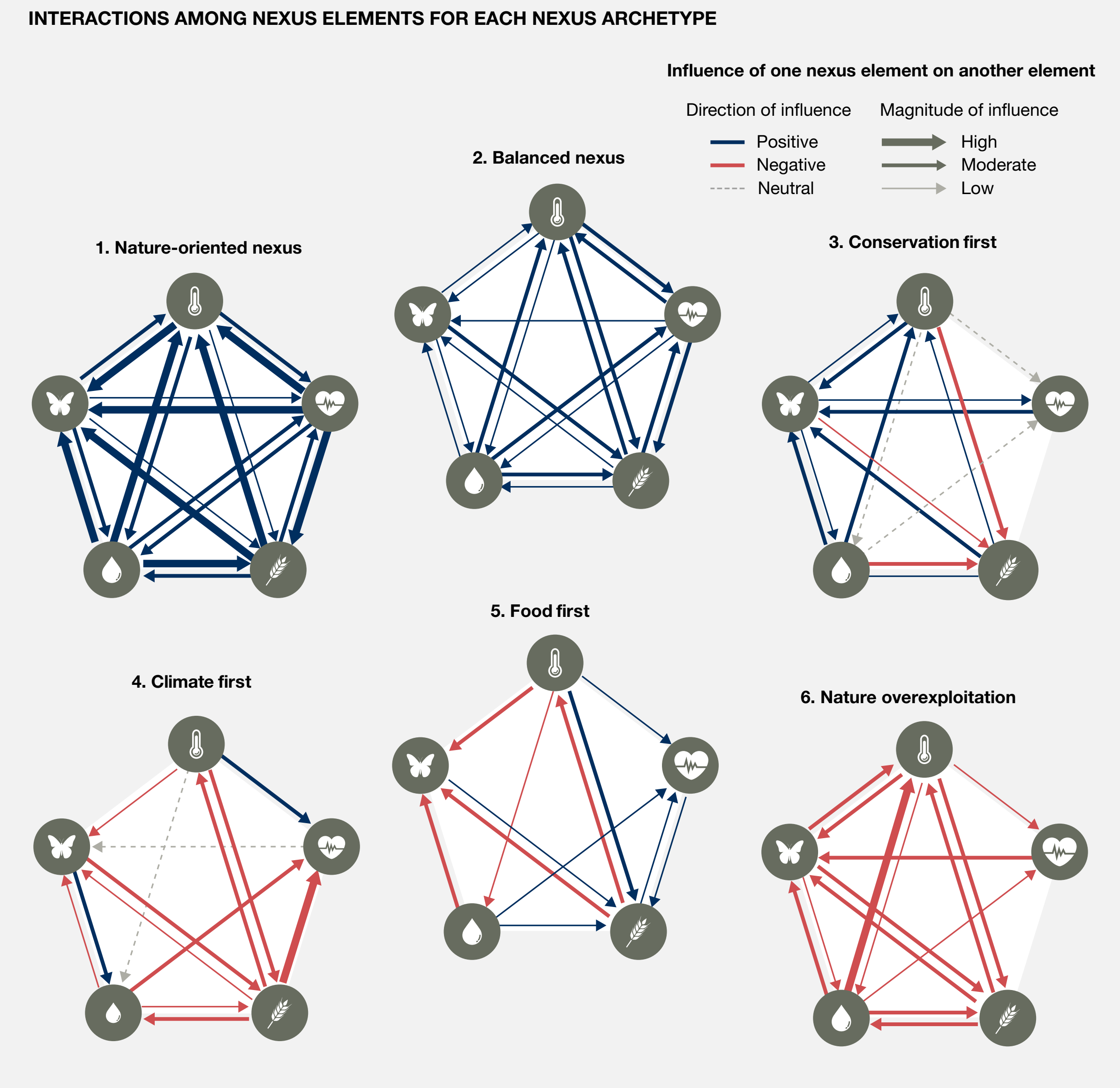


Figure 3 7 **Interactions among the nexus elements for each nexus scenario archetype.**

For each of the six nexus scenario archetypes (1. *nature-oriented nexus*; 2. *balanced nexus*; 3. *conservation first*; 4. *climate first*; 5. *food first*; 6. *nature overexploitation*), how nexus elements influence each other and the direction and average magnitude of these impacts are shown.

Kupkanchanakul *et al.*, 2015; Wöhler *et al.*, 2020). In addition, these scenarios are characterized by sustainable consumption and production (e.g., motivated by policies promoting behavioural change) (Kok *et al.*, 2018; Petzold *et al.*, 2020; Veerkamp *et al.*, 2020), as well as stable to slightly increasing trends in economic growth. Importantly, these scenarios emphasize inclusive economic growth and equity mechanisms to ensure just distribution of benefits across different societal groups. Moreover, sustainability scenarios in the *nature-oriented nexus* archetype include fast development of green technologies **(Figure 3.8)** as well as rapid shift to renewable energy sources. Scenarios failing to implement strong and mainstreamed environmental regulations while emphasizing economic growth at the cost of other sustainability goals result in severe trade-offs between the nexus elements *(conservation first, climate first* and *food first)* **(Figure 3.8)**.

The six nexus scenario archetypes were assessed in terms of the shared response options that emerged from **Chapter 5 (section 5.6.3; Figure 5.6.3).** The response options that were the most represented across all scenarios were area-based conservation of terrestrial and marine ecosystems, followed by reducing pollution and restoring landscapes. Analysing the distribution of response options across different scenario periods showed that response options adopted earlier (e.g., until 2030) were associated with the *nature-oriented nexus* and *balanced nexus* archetypes, and result in positive outcomes across the nexus elements. In contrast, response options adopted late in the future timeline (e.g., until 2100) tend to be associated with the *nature overexploitation* archetype, indicating the negative consequences for nexus elements of acting too late. In the mid-term future scenarios (until 2050), nature conservation, dietary changes and pollution removal tend to feature most frequently, while the long-term future scenarios (until 2100) feature an increasing number of restoration-oriented response options.

	Indirect drivers			
Nexus archetype	**Economic** (GDP)	**Institutional** (Environmental regulation)	**Cultural** (Per capita consumption)	**Technological** (Technological development rate)
1. Nature-oriented nexus	↑	↑	→ *	↑↑
2. Balanced nexus	→	↑↑	→ *	→
3. Conservation first	↑↑	↓	↑	↑
4. Climate first	↑↑	↓↓	→	↑↑
5. Food first	↑	↓↓	↑↑	→
6. Nature overexploitation	→	↓	↑	→

Future trend

- ↑↑ Strong increase
- ↑ Increase
- ↓ Decrease
- ↓↓ Strong decrease
- → Stable

Figure 3 8 **Aggregate trends in indirect drivers represented in the scenarios underlying the six nexus scenario archetypes.**

Arrows in the table represent expert interpretation of the magnitude of trends in indirect drivers across scenarios found in the archetypes, based on the general trends of the underlying SSPs (O'Neill *et al.*, 2017) and the IPBES Global Assessment Chapter 4 (IPBES, 2019). See **Table 3.4** for explanation of how the indirect drivers lead to changes in the nexus elements within each archetype.

* The stable trend in per-capita consumption refers to an average value at the global scale. As consumption is expected to increase in some regions in the future (e.g., in regions currently suffering from malnutrition), this implies decreasing consumption in other regions.

Table 3 4 **The six nexus scenario archetypes and their characterizations.**

Nexus scenario archetype	Number of scenarios [total (terrestrial/ marine)]	Characteristics of the archetype	Example characteristics of the scenarios within the archetype	Example scenarios
Nature-oriented nexus	37 (23/14)	This archetype is broadly characterized by positive outcomes across all nexus elements, and particularly positive outcomes for biodiversity **(Figure 3.6B)**. The archetype is predominantly made up of scenarios with moderate economic growth, sound environmental regulation, curbed increase in per capita consumption and fast technological innovation **(Figure 3.8)** including high conservation targets of 30 per cent.	Mostly scenarios prioritizing conservation or its combination with other sustainable management approaches, considering system interactions. Higher-end protected area scenarios with high effectiveness of protection. Broadly ambitious climate action, and increased adoption of technology.	Arneth *et al.* (2023); Bauer *et al.* (2019); Bertram *et al.* (2018); Brito-Morales *et al.* (2022); Corrales *et al.* (2018); Doelman *et al.* (2022); Henry *et al.* (2022); Humpenöder *et al.* (2022); Jung *et al.* (2021); Krause *et al.* (2018); Melbourne-Thomas *et al.* (2011); Moallemi *et al.* (2022); Mu *et al.* (2002); Odgaard *et al.* (2017); Rasche *et al.* (2022); Sala *et al.* (2021); Tallis *et al.* (2018); Vilas *et al.* (2021a); Wholer *et al.* (2020)
Balanced nexus	31 (21/10)	This archetype is broadly characterized by positive outcomes for all nexus elements, and in comparison to *nature-oriented nexus,* has more positive outcomes for food and health, and lesser but still positive outcomes for biodiversity, water and climate change **(Figure 3.6B)**. This is in part because the ambitions for biodiversity conservation and restoration, supported by strong environmental regulation, are considered alongside sustainable use options, lifestyle and dietary changes, but lower to moderate ambitions for climate action **(Figure 3.8)**. The scenarios in this archetype are fairly equally spread between 2030, 2050 and 2080 – 2100. The scenarios are also spread equally across global and regional scales.	Lifestyle and consumption changes, low emissions, restoration and conservation, and sustainable use of natural resources alongside biodiversity conservation.	Arneth *et al.* (2023); Bertram *et al.* (2018); Bryndum-Bunchholz *et al.* (2020); Corrales *et al.* (2018); Gomei *et al.* (2021); Klinger *et al.* (2017); Kok *et al.* 2018; Krause *et al.* (2018); Melbourne-Thomas *et al.* (2011); Moallemi *et al.* (2022); Mu *et al.* (2022); Odgaard *et al.* (2017); Panagos *et al.* (2021); Perosa *et al.* (2021); Rasche *et al.* (2022); Sala *et al.* (2021); Staccione *et al.* (2023); Tian *et al.* (2018); Vilas *et al.* (2021b); Wholer *et al.* (2020)
Conservation first	29 (21/8)	The scenarios in this archetype are characterized by positive outcomes for biodiversity and climate change, negative outcomes for food, and neutral outcomes for water and health **(Figure 3.6B)**. The archetype includes ambitious action targeting biodiversity and climate change, although these aggregate to a moderate level. The negative food outcome reflects the effects of extending terrestrial protected areas on food production and nutritional health and considerable nitrogen fertilizer reductions. Other factors include weaker environmental regulation, failing to set up a sufficiently holistic and reinforcing system of sustainable management across all nexus elements **(Figure 3.8)**.	Considerable nitrogen fertilizer reductions, ambitious but low protected area effectiveness, decentralization, and medium to high ambition climate action. Also includes expected lifestyle changes.	Arneth *et al.* (2023); Bertram *et al.* (2018); Doelman *et al.* (2022); Henry *et al.* (2022); Humpenöder *et al.* (2022); Jiang *et al.* (2021); Jung *et al.* (2021); Kok *et al.* (2018); Krause *et al.* (2018); Melbourne-Thomas *et al.* (2011); Mu *et al.* (2002); Rasche *et al.* (2022); Staccione *et al.* (2023); Tian *et al.* (2018); Vilas *et al.* (2021a); Vos *et al.* (2021); Zhao *et al.* (2020)

Table 3 4

Nexus scenario archetype	Number of scenarios [total (terrestrial/ marine)]	Characteristics of the archetype	Example characteristics of the scenarios within the archetype	Example scenarios
Climate first	23 (11/12)	This archetype only shows positive outcomes for climate change and health **(Figure 3.6B)**. The scenarios are largely BAU scenarios and economy first type scenarios but with higher levels of ambitions for climate action and some sustainability ambitions. The poor outcomes for biodiversity in this archetype reflect the competition for land arising from some climate change mitigation actions, such as the push for biofuels without wider sustainability considerations, resulting from weak institutions **(Figure 3.8)**.	Medium to higher ambitions for climate change mitigation action but also BAU scenarios such as economy first. Scenarios that rely on technological innovation and solutions as well as changing consumption patterns.	Bertram *et al.* (2018); Blanchard *et al.* (2017); Bryndum-Buchholz *et al.* (2020); Chapman *et al.* (2020); Cinner *et al.* (2022); Coll *et al.* (2020); Filgueira *et al.* (2016); Krause *et al.* (2018); Loetze *et al.* (2019); Okruszko *et al.* (2011); Piroddi *et al.* (2021); Tallis *et al.* (2018); Turner *et al.* (2018); Veerkamp *et al.* (2020); Vilas *et al.* (2021b); Vos *et al.* (2021); Wholer *et al.* (2020)
Food first	21 (9/12)	This archetype shows benefits only for food and nutritional health **(Figure 3.6B)**, resulting from intensified food production and increased per capita consumption **(Figure 3.8)**, with the other nexus elements showing negative outcomes. The scenarios are primarily driven by high impacts of climate change on other nexus elements, and a few instances of impacts of food objectives on biodiversity and climate change. This archetype highlights that despite some ambitions to reduce GHG emissions, climate change impacts will still be felt across nexus elements due to lag effects associated with these impacts.	Scenarios include those focused on ocean warming, economic growth first, coral bleaching events and sectoral policies. Although there are a few scenarios with high ambition for climate action and collaborative governance, most are isolationist and sectoral, and prioritize continuation of current trends.	Bauer *et al.* (2019); Boyce *et al.* (2020); Corrales *et al.* (2018); Gomei *et al.* (2021); Kok *et al.* (2018); Melbourne-Thomas *et al.* (2011); Moallemi *et al.* (2022); Steneck *et al.* (2002); Veerkamp *et al.* (2020); Vilas *et al.* (2021b); Visser *et al.* (2019)
Nature overexploitation	45 (24/21)	This archetype is characterized by negative outcomes for all but one nexus element (water, which shows a neutral outcome) **(Figure 3.6B)**. The scenarios largely resemble SSP5 ("Fossil-fueled development"), indicating a world with weak environmental regulation, driven by preferences for economic growth and technological solutions, with low ambitions for climate action, as well as SSP2 ("Middle of the road") and SSP3 ("Regional rivalry") **(Figure 3.8)**. As with *food first*, nearly all scenarios are characterized by climate change impacts on other nexus elements. This implies both the negative impacts of climate change on other nexus elements, but also that climate change becomes more critical.	Largely "Fossil-fuelled development" scenarios, with political and societal attitudes assuming that environmental challenges can be fixed later. Coral bleaching events. There are also cases of sustainably managing fisheries, forests and croplands, but these seem to be overshadowed by an overwhelming focus on current trends and practices exacerbated by weak environmental regulation.	Arneth *et al.* (2020); Blanchard *et al.* (2017); Boyce *et al.* (2022); Carlson *et al.* (2022); Chapman *et al.* (2020); Cheung *et al.* (2021); Cheung *et al.* 2022; Coll *et al.* (2020); Doelman *et al.* (2022); Filgueira *et al.* (2016); Fischer *et al.* (2014); Humpenöder *et al.* (2022); Loetze *et al.* (2019); Melbourne-Thomas *et al.* (2011); Okruszko *et al.* (2011); Prudhomme *et al.* (2020); Rasche *et al.* (2022); Tittensor *et al.* (2021); Veerkamp *et al.* (2020); Zhao *et al.* (2018)

3.7.2 Synthesis in relation to global policy targets

This section addresses the policy relevant question identified for **Chapter 3** "how might the nexus elements and interdependencies change in the future, and what pathways and scenarios could lead to sustainable futures that address the nexus elements synergistically with minimal trade-offs?". Overall, scenarios with positive outcomes across the nexus have very different implications for policy compared with scenarios that focus only on a single nexus element This underscores the important role of nexus scenarios in providing the evidence to support the achievement of policy goals and decisions (P. A. Harrison *et al.*, 2016).

Figure 3.9 shows how each nexus scenario archetype contributes to the 17 SDGs through the proportion of individual scenarios within an archetype that contribute to either negative, neutral or positive outcomes. This reflects a 'general direction of travel' rather than the achievement of an SDG in 2030 given the different time periods associated with the scenarios. **Table 3.5** shows the number of scenarios per archetype and SDG, highlighting that a greater number of scenarios map onto the SDGs that are directly related to the nexus elements (i.e., SDG2, SDG6, SDG13,

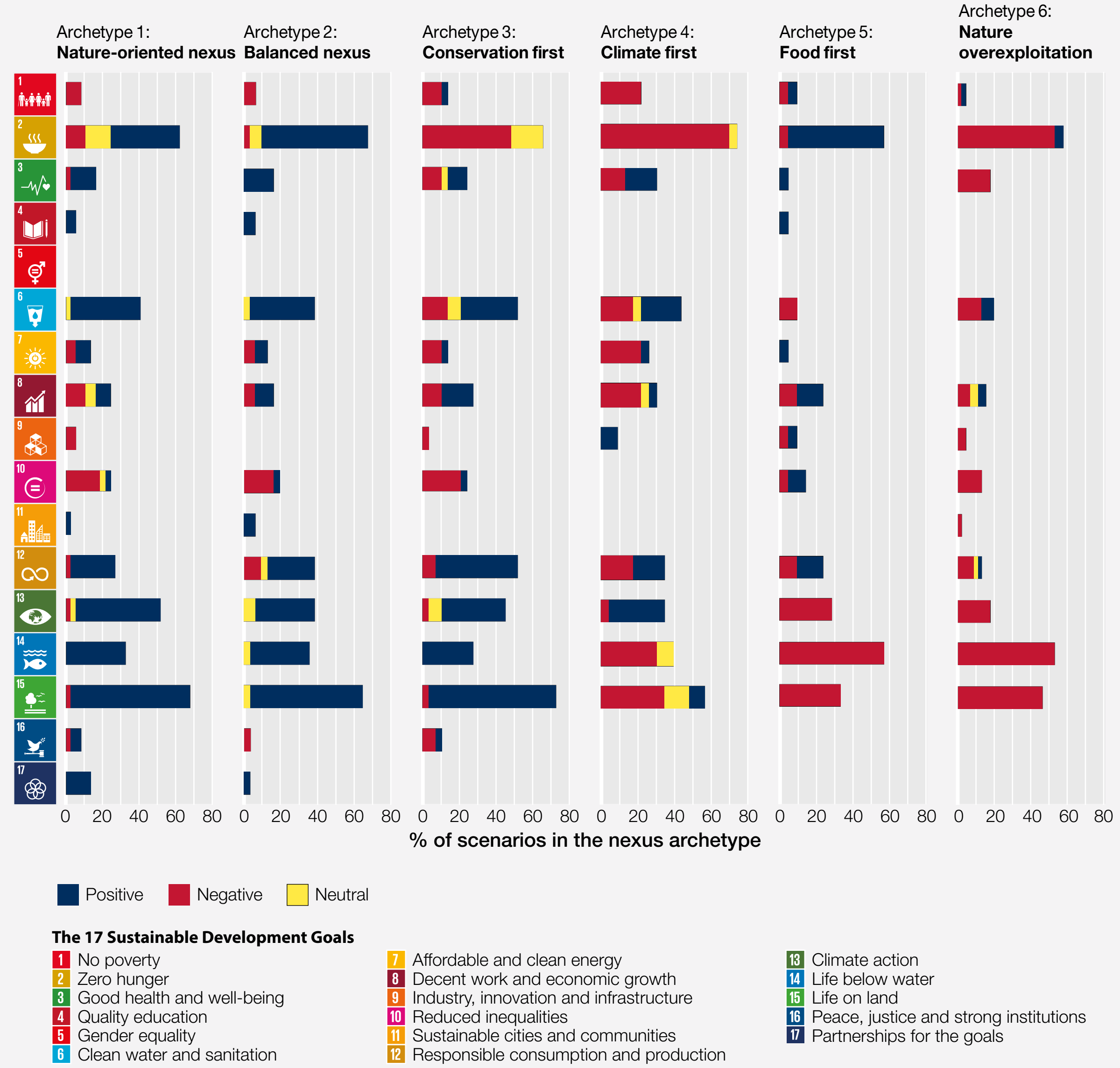


Figure 3.9 **Proportion of scenarios within each archetype that have negative, neutral or positive outcomes for the Sustainable Development Goals.**

The number of scenarios in each proportion is given in the **Table 3.5**. Note that many of the scenarios are time-independent or are referenced to different time horizons.

Table 3 5 **Number of scenarios with relevance to each Sustainable Development Goal (either positive, neutral or negative implications).**

Colour coding (light to dark grey): a) counts from 1 to 9, b) counts from 10 to 20, c) counts from 21 and above. Blank cells are missing values meaning that no scenarios covered this SDG and hence missing values represent a knowledge gap.

Arche-type	Total number of scenarios with negative, neutral or positive implications per SDG															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14/15	16	17
Nature-oriented nexus	3	21	5	2		15	5	8	2	9	1	10	18	36	3	5
Balanced nexus	2	21	5	2		12	4	5		6	2	12	12	31	1	1
Conservation first	4	18	7			15	4	7	1	7		15	12	28	3	
Climate first	5	17	7			10	6	7	2			8	8	22		
Food first	2	13	1	1		4	1	7	3	4		5	8	21		
Nature overexploitation	2	28	8			9		9	2	6	1	6	10	47		
Total	18	118	33	5	0	65	20	43	10	22	4	56	52	185	7	6

SDG14 and SDG15), compared to other SDGs. Several important trends emerged from this analysis. In general, negative values increase (and positive values decrease) for the SDGs from the nature-oriented to nature-negative archetypes, as do the number of SDGs without scenario data. This implies that archetypes that have more positive outcomes for biodiversity and have fewer trade-offs with the other nexus elements also contribute more positively across the SDGs. However, trade-offs are apparent for some SDGs in all archetypes. SDG1 *(no poverty)* and SDG10 *(reduced inequalities)* are largely negative across all archetypes, although the *food first* archetype is partly positive for SDG10. Hence, even the scenarios within the nature-oriented archetypes inadequately include actions for dealing with the issues of poverty and social inequalities. SDG9 *(industry, innovation and infrastructure)* is negative in the *nature-oriented nexus* and missing in *balanced nexus* archetypes, although it is positive in *climate first* and partly positive or neutral in *food first*. This likely arises from the negative impacts of industry on biodiversity, but also the more economic focus of *climate first* and *food first*.

SDG5 *(gender equality)* is absent from all scenarios and archetypes included in this analysis, which is a significant knowledge gap among the nexus scenarios. Furthermore, SDG16 *(peace, justice and strong institutions)* and SDG17 *(partnerships for the goals)* are missing in the *climate first, food first* and *nature overexploitation* archetypes, although these SDGs are critical prerequisites for the response options considered in **Chapter 5**.

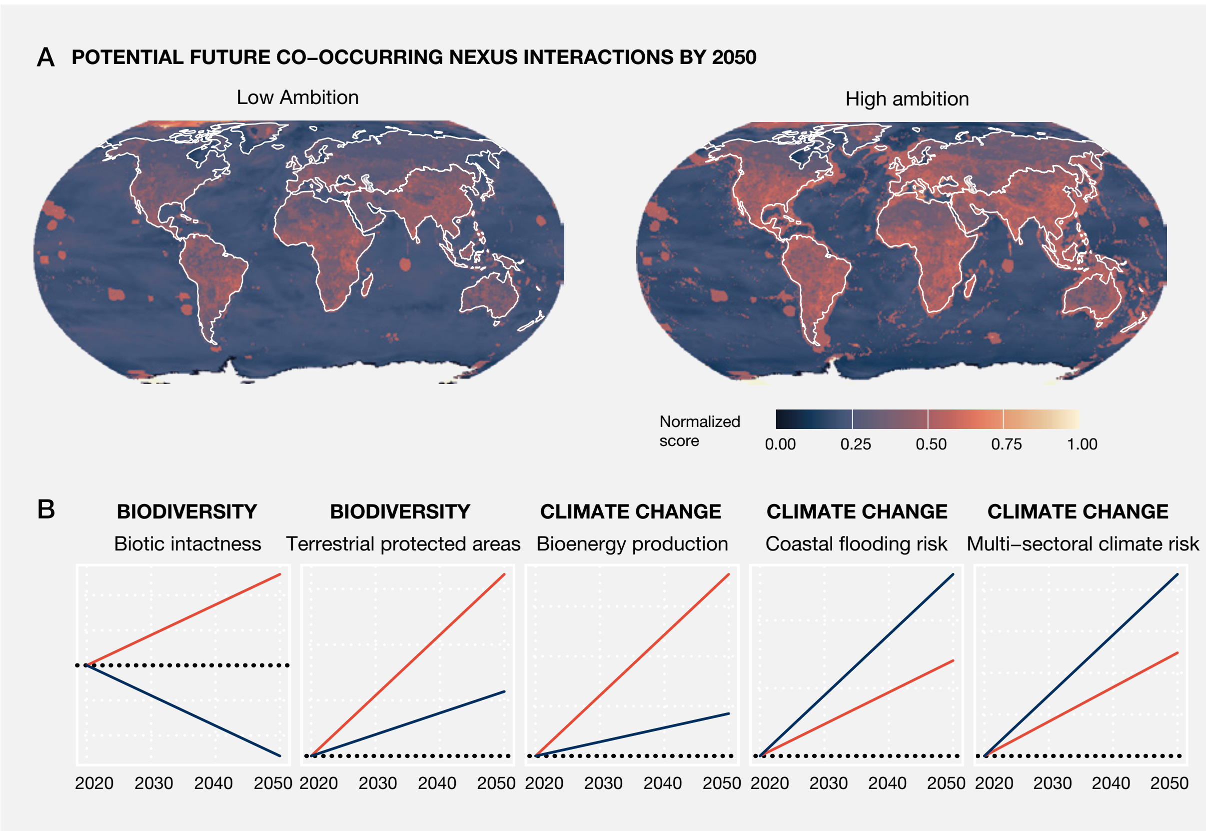
SDG13 *(Climate Action)* links directly to the Paris Agreement. The archetype analysis demonstrates the negative impacts of climate change across the nexus elements, which supports the need for urgent climate action to avoid the worst effects of climate change on biodiversity and the other nexus elements. However, the analysis also demonstrates that high levels of climate change mitigation through e.g., reforestation/afforestation and BECCS, can have negative impacts on biodiversity. Hence, policy that balances the goal of mitigating climate change while minimizing the negative impacts of mitigation actions would have the greatest benefits for biodiversity and the other nexus elements. The data also indicate that policy to mitigate climate change is more effective in future scenarios in which trade-offs across the nexus elements are minimized.

SDG14 *(Life Below Water)* and SDG15 *(Life on Land)* link directly to the Kunming-Montreal Global Biodiversity Framework goals. The *conservation first, climate first* and *food first* archetypes demonstrate the importance of connecting food and biodiversity policy to avoid negative trade-offs. Furthermore, *nature-oriented nexus* and *balanced nexus* have the largest benefits for SDG14/15, with implications for how biodiversity policy might be implemented both for the benefit of nature, but also the other nexus elements. The archetype analysis and other literature sources support the policy goal of 30 per cent protected areas if these are efficiently managed for nature conservation. Higher levels of protected areas (up to 50 per cent) would have greater biodiversity benefits, but likely many more trade-offs across the other nexus elements. Marine systems are an exception to this, for which further protection (if implemented effectively) would have co-benefits across all the nexus elements, including food, through enhanced fish stocks. Reducing inequalities is central to many sustainable pathways with just and inclusive approaches to conservation and restoration needed to attain sustainable pathways (Chan *et al.*, 2020).

Box 3 9 Potential future co-occurrence of nexus interactions.

Adaptation to a changing environment has happened for An explorative spatial analysis of potential future co-occurrence of different two-way interactions between nexus elements (e.g., biodiversity-climate change, water-health, water-food) was conducted across different geographic regions. The assessment showed that based on projected indicators from the reviewed scenarios, there is a high potential for different types of future co-occurrences of nexus interactions globally, and that this potential tends to increase with pathways that are more ambitious with respect to sustainable futures (e.g., in terms of climate mitigation). This indicates that nexus interactions need to be considered in the future even under ambitious policy pathways. Two different scenario pathways were used: a low ambition (e.g., SSP5-8.5) and a high ambition (e.g., SSP1-2.6) pathway for climate change mitigation. For scenario data not explicitly following an SSP or RCP pathway, the respective scenario data was mapped to low and high policy ambition respectively.

Figure 3.10 (A) shows potential future co-occurrence of nexus interactions rendered as an aggregate difference between the projected state of scenario indicators in 2050 and their current levels. While a high normalized score indicates potential co-occurrence of nexus interactions, it is important to note that it does not imply any specific direction (e.g., synergistic) or magnitude (e.g., loss or gain) of the interactions. Using the same approach of comparing projected 2050 levels with the current baseline, **Figure 3.10 (B)** assesses the future potential for nexus interactions using additional indicators for which projections were publicly available. **Figure 3.10 (C)** illustrates scenario data gaps compared to at least one indicator per nexus element, realm and policy ambition.



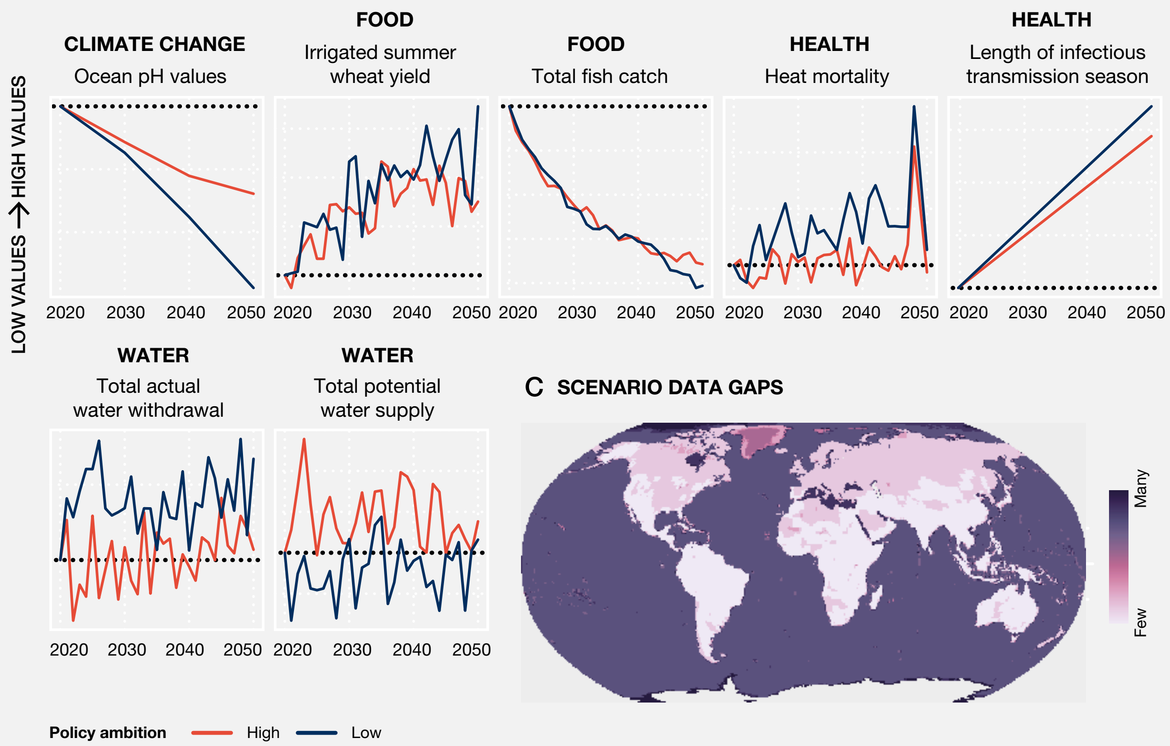


Figure 3 10 **Future potential co-occurrence for nexus interactions.**[2]

3.7.3 Implications of Indigenous and local knowledge for the nexus scenarios

Indigenous Peoples and local communities have a unique understanding of nexus connections **(Chapter 1, section 1.2.2)** and provide alternative aspects to scenarios in terms of future outcomes and their importance and value. One of the objectives of the NFF is to support the generation of scenarios that engage with ILK or that are developed with IPLC participation, by focussing on values, particularly relational values (e.g., the nature as culture/one with nature value perspective in the NFF) (Pereira *et al.*, 2020). Scenarios may also show unique outcomes for Indigenous populations. For example, a study of the effects of climate change on the Saami people of northern Europe showed that these effects can become more serious compared to other populations in the area because of unique population characteristics and culture (Jaakkola *et al.*, 2018). Knowledge co-production and sharing can direct the development of more inclusive future scenarios by including multiple ways of knowing and participatory planning (Armitage *et al.*, 2011; Maraud & Roturier, 2023). Future scenarios that recognize environmental sustainability for IPLC can support achievement of the biodiversity targets in a socially equitable way (Sarkki *et al.*, 2023). Hence, engaging with diverse visions for the future can support better governance of nexus interactions and lead to more sustainable resource management approaches and more just outcomes for nature and people (Falardeau *et al.*, 2019; Sarkki *et al.*, 2023).

3.7.4 Scenario methods for supporting nexus decision-making

The scenarios assessed in this chapter were developed using a wide range of methods. This includes the scenario framing itself (e.g., SSPs/RCPs, NFF), the methods used to construct narratives (e.g., participatory approaches, expert elicitation) and the qualitative methods (e.g., mental models, causal loop diagrams) and quantitative models (e.g., integrated assessment models, agent-based models) used to characterise narratives. This section discusses these alternative (often complimentary) methods within the context of informing nexus decision-making.

3.7.4.1 Scenario framing

Many of the scenarios reported here were based on the SSP/RCP scenario framing that emerged from the climate change assessment community. The SSPs/RCPs have been used extensively to inform climate policy, notably through IPCC assessments and Special Reports. While attempts have been made to adapt the SSPs/RCPs for application in biodiversity assessments, the fundamental climate-focus of this scenario framing limits its applicability in biodiversity decision-making. Consequently, more nature-focused scenario framings have emerged such as the NFF **(Box 3.2)**. In contrast to the exploratory SSPs, the NFF takes a normative approach based on alternative nature value perspectives. This is an attempt to make the approach more solutions-orientated with a focus on nature-oriented futures that can inform decision-making. How this might happen in practice is likely to emerge through time, as this relatively recent approach is used more extensively. Developments to advance the use of the NFF in decision-making could include the creation of NFF narratives based on interpretation of indirect drivers for the alternative value perspectives, and quantification of the direct drivers and biodiversity consequences using models (see **section 3.7.4.3**).

Other approaches to scenario development are more explicit about policy targets, including, for example, protected area targets of 30 per cent or 50 per cent (e.g. Henry *et al.*, 2022). Such approaches are highly policy relevant and are also able to demonstrate the trade-offs and co-benefits of achieving policy targets. A commonly applied and useful scenario framing is a BAU scenario reflecting the continuation of current trends. BAU scenarios are useful to decision-making by demonstrating the consequences of inaction since these scenarios inevitably continue the trend of declines in biodiversity.

3.7.4.2 Qualitative methods

Methods in the construction of scenario narratives are often based on either expert judgement (i.e., based on the knowledge of the scenario developers themselves) or through participatory approaches with key stakeholders (e.g., P. A. Harrison *et al.*, 2015). Participatory approaches aim to legitimise narrative development by drawing on knowledge from outside the academic community. Such approaches are generally based on stakeholder workshops or focus groups, and other means of knowledge elicitation, such as surveys. Participatory approaches also draw on qualitative approaches to represent causal relationships within socio-ecological systems, e.g., using causal loop or system diagrams, and/or by developing semi-quantitative future trends in key drivers.

Other qualitative methods used in scenario development include literature-based approaches. An example of this is the green shoots approach (Arneth *et al.*, 2023) that captured the nexus interactions between biodiversity, food and climate change through a literature-based visualisation of potential scenario space. This approach has the potential to support decision-making in a similar way to the burning embers visualisations of the IPCC.

3.7.4.3 Quantitative models

Modelling is a core part of many scenario development studies. Models are commonly used to translate qualitative narratives into quantitative system variables describing direct drivers (e.g., land-use change, climate change, pollution, nature resource extraction) and their subsequent impacts on biodiversity and the other nexus elements. Modelling in support of nexus decision-making typically applies some form of integrated assessment to represent the dynamics within socio-ecological systems (Rounsevell *et al.*, 2021) to cover the range of nexus elements. Integrated assessment models (IAMs) are global-scale models that originate from climate change assessment with their focus on representing the energy-economy system. IAMs also include representation of the land system and have increasingly been coupled to ecological models (e.g., Leclere *et al.*, 2018) to explore biodiversity impacts.

Other integrated assessment approaches have focused on representing the land system, biodiversity and ecosystem processes in support of biodiversity policy. Examples include LandSyMM at the global scale (Rabin *et al.*, 2020) and the integrated assessment platform (IAP) (P. A. Harrison *et al.*, 2016) at the continental (European) scale. LandSyMM combines global land system, vegetation and ecosystem modelling to simulate land-use and management change, ecosystem functioning and trophic cascades for terrestrial environments. LandSyMM has been applied to policy-relevant nexus topics such as protected areas, food security and nutritional health (Henry *et al.*, 2022) and dietary impacts on biodiversity including displacement effects (indirect land-use change) (Henry *et al.*, 2019). The IAP combines land, water, species and ecosystem functioning meta-models in an integrated model that has been used to address nexus decision-making with key stakeholders with a focus on climate change impacts and adaptation (P. A. Harrison *et al.*, 2015). Another example at the continental (European) scale applied an agent-based model (ABM) with a network optimisation approach to explore policy targets for protected areas (30 per cent) and the implications of these for food security within the context of climate change (Staccione *et al.*, 2023).

None of these models include representation of the marine realm. Ecological models do, however, exist for marine systems, and have been applied in support of decision-making, especially for fisheries management and the establishment of marine protected areas. Recent ensemble modelling has substantially contributed to scenario testing in the marine realm (e.g., Lotze *et al.*, 2019; Tittensor *et al.*, 2021).

Integrated scenarios and models can support complex policy or business decisions through the holistic assessment of alternative response options and their environmental, social and economic outcomes, taking account of synergies and trade-offs between different sectors or nexus elements (P.

A. Harrison *et al.*, 2023; Mosnier *et al.*, 2023a). As such integrated models have been used by national governments to directly inform nexus decision-making and related policy design. An example is provided in **Box 3.10** for the Welsh Government who use an integrated modelling platform to explore, stress-test and iterate business-critical nexus policies prior to final design and implementation.

3.7.4.4 Decision support tools

Scenarios can provide the starting point for further analysis in support of decision-making using decision support tools (Rounsevell *et al.*, 2021). Many decision support tools exist for this purpose (see also **Chapter 4, section 4.6**). Optimization approaches maximize an objective function and include simple approaches such as cost benefit analysis or more sophisticated approaches such as info-gap. Multi-objective approaches focus on the competing values and preferences of decision-makers using deliberative or sometimes hybrid deliberative/quantitative methods. Integrated approaches aim to combine deliberative and quantitative tools through, for example, adaptive management and structured decision-making (Rounsevell *et al.*, 2021).

Systematic conservation planning (SCP) using decision-support tools that provide optimization of multiple outcomes (e.g., meeting biodiversity targets while minimizing opportunity costs under different climate scenarios) based on probabilistic approaches has been used increasingly throughout the world (e.g., Marxan, Zonation, prioritizr). There are however also considerable gaps and uncertainties behind the identification of optimal nature conservation practices, with some arguing that true synergies and win-win situations are relatively rare in practice owing to confounding factors (Hegwood *et al.*, 2022). Here, novel technologies such as reinforcement learning for environmental management problems might have the potential to account for non-linear and complex decision-making problems (Lapeyrolerie *et al.*, 2022).

Box 3 10 **Embedding the use of integrated scenarios and models into the policy cycle of the Welsh Government.**

Integrated scenarios and models can be used to support decision-making by increasing understanding of the complexity of nexus interactions and how response options can be designed to foster synergies in environmental, economic and social outcomes across nexus elements. However, despite the potential benefits of integrated scenarios and models for facilitating integrated, rather than siloed, policy-making, they have rarely been used to design and evaluate policy within national governments. One example of where this has happened is in the development of the ERAMMP Integrated Modelling Platform (IMP), which was co-created by academics in partnership with the Welsh Government to support the design of new "business-critical" policies focused on agriculture, land-use and natural resource management. The value of the nexus approach for providing evidence for emerging policy needs was recognised by the Welsh Government due to their current legislation, particularly the Wellbeing of Future Generations (Wales) Act 2015 and Environment (Wales) Act 2016, both of which put an emphasis on addressing multiple outcomes in a holistic way.

The IMP is a linked modelling system which includes 11 models representing different aspects of agriculture, forestry, land-use, several NCP (climate regulation, water quality and air quality – including health impacts – and their valuation) and biodiversity. The model is being actively used by the Welsh Government to explore, test and iterate business-critical policy ideas prior to final policy design and implementation. In particular, it is currently being used to support the design of a new Sustainable Farming Scheme (https://www.gov.wales/sustainable-farming-scheme-guide), which will be the main source of future Government support for farmers in Wales.

The successful integration of the IMP within the policy cycle of the Welsh Government relied upon:

- An iterative co-creation process through a long-term partnership between government and the modelling team to build trust and understanding in a complex integrated model and its outputs.
- Transparency of the model and its assumptions, including following government approved quality assurance processes for the use of models in policy decisions.
- Flexibility of the modelling approach so that it can be rapidly adapted to changing policy needs in near real-time, enabling timeliness of model runs that are delivered at a pace that is able to inform quickly evolving policy needs.

These attributes have facilitated cultural change within the Welsh Government where policy development is increasingly more integrated, evidence-based and iterative, with the policy and evidence teams from across nexus elements having the space to challenge each other as the thinking evolves. As described by a key Welsh Government stakeholder, *"The IMP has brought extremely complex and often seemingly unrelatable evidence directly to the policy teams in a format which is accessible. This has enabled a step change to take place where high quality evidence is central to policy design".*

Box based on (P. A. Harrison *et al.*, 2023).

3.7.5 Uncertainties

Scenarios are usually created based on plausible assumptions of how the future might play out across different pathways and value systems (Harmáčková *et al.*, 2022, 2023). Most quantitative and qualitative assessments of future interactions across the nexus are based on some kind of model or assumptions, including mental models, which need to be critically evaluated in terms of their uncertainties (Rounsevell *et al.*, 2021). Four generic categories of uncertainty in scenarios can be distinguished: (i) uncertainties in the data and parameters underlying a model, including down propagation of errors (Rounsevell *et al.*, 2021); (ii) uncertainties in the model estimation, and aleatory and epistemic uncertainty in scenarios (Dunford *et al.*, 2015); (iii) uncertainties in interaction strength and direction between elements of the nexus; (iv) uncertainties resulting from indirect drivers or non-considered and latent factors affecting the scenarios (Payne *et al.*, 2016).

Within these generic categories there are numerous uncertainties in quantitative and qualitative scenarios that need to be critically evaluated (Rounsevell *et al.*, 2021). In the context of the nexus and linkages between individual sectors, comparably little focus has been placed on the magnitude of interactions (weak to strong) and their directionality (linear, non-linear, bidirectional). Sources of uncertainty explode for long-term projections beyond 2100 include differing feedbacks between geographic regions and lagged effects on the global carbon cycle (Koven *et al.*, 2022; Lyon *et al.*, 2022).

Furthermore, there is a need to further maximize consistency and processing pipelines for scenario baselines through harmonization of input data and parameters and further integration between models (P. A. Harrison *et al.*, 2018). Regionally transferable, consistent and scalable fully coupled frameworks would alleviate some of the uncertainties behind global scenarios in the water-energy-land nexus (N. Johnson *et al.*, 2019).

Finally, tested scenarios including multiple nexus elements only include specific response options and rarely test the outcomes of combining (or bundling) multiple response options (e.g., combining fisheries changes in effort, placement of MPAs and restoration actions). Real implementation of response options will likely imply the combination of actions in a bundle or sequence (see **Chapter 5.6, section 5.6.4**), which are not fully tested in available scenarios yet.

3.7.6 Knowledge gaps and research needs

The assessment process has highlighted many gaps in the current knowledge base about future scenarios of the nexus (including ILK), and this section discusses these gaps with respect to future research needs and opportunities.

3.7.6.1 Knowledge gaps related to concepts and methods

A nexus approach implies the need to take a systemic approach in analysing the future. This includes integrating the different elements of the nexus within a socio-ecological perspective that would support the recognition of trade-offs, thresholds and synergies between sectors and their effects and impacts. It also includes developing scenarios that better link processes across realms (e.g., from terrestrial to freshwater to marine) and represent multiple management activities (e.g., placing a protected area and managing fishing effort simultaneously). In addition, consideration of the nexus at the planetary scale is important, for example, in accounting for the globalization of supply chains, food security, overexploitation, climate change, pandemics and water cycles.

Inclusion of visions embedded in ILK is also critical to implementing a nexus approach and currently the participation of ILK holders is often lacking in scenario conceptualization, development and planning. In general terms there is a lack of scenarios based on positive outcomes or visions that are plausible in terms of implementation, especially policy implementation scenarios that could assist in understanding how stylized scenarios or targets might be realised across different scales.

Modelling tools play a crucial role in many scenario studies, but all models are ultimately approximations of reality and can differ in model structure, parameterization, input data, error propagation and the interpretation of model outputs for decision-making (Rounsevell *et al.*, 2021). There is a clear need, therefore, to further develop modelling tools that better account for nexus interactions, that can simulate scenarios at a range of spatial scales (global, regional, local) and that account for inherent modelling uncertainties (Payne *et al.*, 2016). This is especially the case for large scale modelling of pathways to sustainable outcomes within the nexus. Many current modelling tools are better able to quantify exploratory scenarios, rather than the pathways leading to normative, target-seeking scenarios. Although rarely implemented at present, models may need to be adapted to better represent the diversity of world-views implicit within different scenario storylines. In many cases, models are used to quantify future worlds and their nexus interactions that are unprecedented in the historic record, requiring fundamental changes to model architecture, as well as parameterization to better reflect these alternative future contexts. Models also need to improve their ability to deal with adaptation and adaptive learning (by individual people and collectively as societies) to account for societal feedback processes across nexus elements. In particular, perspectives from IPLC and stakeholders need to be included, and methodologies developed to do this accurately and equably. The recent growth in behavioural, agent-based models that go beyond economic behaviour alone provide a novel way forward in this respect.

As well as further developing modelling concepts, there are technical issues to consider in future model applications. Many problems of future interactions across the nexus require huge amounts of computational resources that exceed the capabilities of today's computers. Future improvements of computation capacity, including low-cost solutions, are needed to further scenario analysis and modelling studies (Steenbeek *et al.*, 2021). For example, a 54-qubit quantum computer can solve in minutes a problem that would take a classical machine 10,000 years (Arute *et al.*, 2019). In the meanwhile, intelligent computing can improve the accuracy of quantum computing. Thus, quantum machine learning would greatly improve model simulation speed and accuracy of future interactions across the nexus, which could be helpful in supporting efficient decision-making, especially for real-time local-scale decisions, such as through the development of digital twins (Yue *et al.*, 2022, 2023). An alternative approach is the use of crowd computing, as has been applied in climate modelling. However, those resources are mostly not available to the Global South and developing states, raising concerns about equitable access to knowledge and scenario planning and execution.

3.7.6.2 Knowledge gaps related to specific nexus elements

Knowledge gaps related to assessing future interactions among nexus elements using scenario approaches are described in **Table 3.6**, structured by nexus element.

Table 3 6 **Knowledge gaps related to the nexus elements.**

Nexus element	Theme	Nexus-related knowledge gaps identified in the scenario literature
Biodiversity	**Biodiversity loss**	Lack of understanding of the consequences of biodiversity loss on other nexus elements (water, food, health, climate change), e.g., the effect of soil biodiversity loss on crop yields, the influences of changing macrophyte abundance for freshwater quality and cascading effects of biodiversity loss in the food web. Tackling this gap requires further advances in model coupling and scenarios that are able to capture such feedbacks.
	Freshwater and marine realms	Lack of understanding of the role of biodiversity in nexus interactions in the freshwater and marine realms, particularly for interactions between more than three nexus elements, as well as for interactions across domains, e.g., from terrestrial to freshwater to marine. For instance, missing knowledge on the nexus impacts of expanding from industrial fisheries to other types of fishing, aquaculture, marine planning including MPAs, and eutrophication, particularly in the deep sea (> 200 m depth).
	Restoration	Lack of scenarios of ecosystem restoration that account for impacts on other nexus elements, e.g., trade-offs with food security and co-benefits with carbon stocks and climate change mitigation.
	Nature conservation	Scenarios normally include one response option at a time, but it is likely that several options will be needed together (e.g., restore, protect, sustainably exploit). More evidence is needed on how specific interactions between nature conservation and other nexus elements could play out, especially in the context of confounding factors and complex future dynamics. A considerable shortcoming of many studies involving future conservation areas is that they consider nature conservation only as a model constraint, e.g., to estimate where certain activities are allowed and where they are not. This omits the possibility of nature conservation areas providing co-benefits across the nexus, thus increasing the uncertainty in potential synergies with other sectors in future scenarios. Future work could more comprehensively investigate the synergies between the benefits that nature conservation provides and the targets from other nexus elements.
Water	**Water quality**	Lack of scenarios of improvement in water quality in the terrestrial and freshwater realms limits insights into impacts on health and biodiversity. Current scenarios lack evidence on the effect of HABs on marine ecosystems and the impact of plastics in the oceans, including how they interact with other nexus elements, point and non-point sources of pollution, and freshwater conservation.
	Water quantity	Assessing changes in the impact of river runoff on marine ecosystems is challenging due to poor-resolution maps (Gao *et al.* 2023; Tittensor *et al.* 2021).
	Water demand	Water demand studies usually include food and health impacts, but biodiversity trade-offs are rarely considered, despite sometimes describing habitat impacts. The equitable management of trade-offs between water supply and water demand will be an increasing challenge under future climate change, which would benefit from further research.

Table 3 6

Nexus element	Theme	Nexus-related knowledge gaps identified in the scenario literature
Water	**Invasive species**	Further research is needed to develop scenarios of invasive species to understand where and when species are likely to expand their distributions and become established in new areas due to climate change, and the positive or negative implications of these range expansions on other nexus elements, such as biodiversity and food (IPBES, 2023a).
	Nature-based solutions	Better scenarios of nature-based solutions, such as natural wetlands and reforestation, may contribute to understanding the balance between biodiversity, water, health and the impacts of climate change. However, knowledge gaps still exist on the effectiveness of nature-based solutions, especially the trade-offs and synergies concerning water management, biodiversity, health, social and economic issues, and on case studies in the Global South, as well as comparisons with non-nature-based alternatives (Chausson *et al.*, 2020).
	Sustainable water use	Lack of sustainable water scenarios and their role in global water security, food security and biodiversity. Water targets for sustainability – accomplished through water reuse (Kookana *et al.*, 2020), conservation, policy mechanisms, government transformations, economic incentives, infrastructure improvement, innovative irrigation, wastewater, agricultural best management practices and land use patterns, and integrated water management – are expected to have synergies with food, health and biodiversity. While the literature supports water targets in terms of visions, these are rarely quantitative. Further research is needed on how scenarios can support the consideration of biodiversity and healthy ecosystems in water, energy, agriculture and other sectors (Chivenge *et al.*, 2015; Rockström *et al.*, 2014; Rong *et al.*, 2021; Rosegrant *et al.*, 2009).
Food	**Spatial scales and contexts**	Most of the nexus scenario studies on food are conducted at the global scale level. There are limited regional or local scale studies in regions with globally important biodiversity (e.g., southeast Asia and Sub-Saharan Africa). Given the diversity of food cultures, more research is needed to reflect the characteristics of regional and local food systems in future scenarios. Additionally, most diets used in dietary shift scenarios are not representative of the diversity of food systems from around the world. As such studies are needed which highlight dietary shifts based on contextually relevant and socio-culturally accepted diets that also conform to environmental conditions in the areas of concern.
	Holistic nexus approach	Previous scenario studies have focused on uncertainty for a limited stage of the whole food system value chain. Future scenario studies need to explore the socio-economic, political and technological uncertainties involved in food trade and processing since these stages could have a large impact on consumption and production. As integrated food system approaches involve diverse dimensions from production to consumption, extensive and detailed analysis of uncertainties is required to explore potential and plausible futures. For example, uncertainties in the assumptions for population growth, technological change and cropland degradation were found to be the most important for global cropland, while uncertainty in food consumption and climate change had less influence on the results (Engström *et al.*, 2016).
Health	**Missing nexus scenarios related to health**	There are fewer scenarios that include health in the nexus. This could include scenarios on tick-borne diseases related to wildlife associated with forest ecosystems, West Nile fever linked with water bird populations, highly pathogenic avian influenza from poultry and swine, Rift Valley fever from cattle, Middle East Respiratory syndrome from dromedaries (MERS), Severe Acute Respiratory Syndrome (SARS) from palm civets, Q-fever from goats, and other infectious diseases for which captive animals act as a reservoir species or stepping stone species.
	Quantitative studies	The impacts on health of concurrent future changes in biodiversity, water, food and climate have not been quantified. Quantitative models of global health generally depend on individual risk factors and socio-economic trends and do not yet account for interactions across the nexus. On the other hand, models investigating impacts of global environmental changes on health typically do not account for socio-economic or health system changes (Weber *et al.*, 2023). Limited quantitative estimates of health impacts are available for selected pathways linking climate change and health.
	Zoonoses	There is a general lack of knowledge about the future interactions of risk factors of relative risks of zoonosis emergence under contrasting approaches to meeting livestock product demand and on pathogen burden of high-risk wild species variation across higher and lower yielding production landscapes (Bartlett *et al.*, 2022).
	Mental health	While a growing body of literature reveals the importance of conserving green and blue space in our living environment for human mental health, future interactions across the nexus with respect to mental health are lacking.

Table 3 6

Nexus element	Theme	Nexus-related knowledge gaps identified in the scenario literature
Climate change	**Holistic nexus approach**	Most evidence on future climate change impacts across the nexus shows that there are multiple hazards resulting from climate change and that risks of impact are reduced with climate change mitigation. Delayed actions and reduced portfolios of fewer mitigation measures make trade-offs across the nexus more likely. Nevertheless, despite increasing evidence and much research focus on investigating potential climate change mitigation options, many aspects of the nexus from a climate change perspective remain unknown or are only approximated. Notably much of the evidence base focuses on the impacts of climate change on single or multiple sectors (IPCC, 2022a), but often miss climate change mitigation efforts. A holistic approach to the outcomes of climate change mitigation on a planetary scale, for example, that integrates impacts and associated synergies and trade-offs across realms is not developed. Furthermore, considerable gaps exist with regards to potential mitigation efforts towards interactions among future nexus elements, and particular synergies and trade-offs are often ignored (P. A. Harrison *et al.*, 2016). In addition to increasing risk from multiple climate hazards, a greater level of warming has also been projected to increase uncertainty and complexity of impact pathways as interactions between nexus elements become increasingly non-linear (Koven *et al.*, 2022; Lyon *et al.*, 2022), which would benefit from further research.

3.8 CONCLUSION

Understanding future interactions between nexus elements through the analysis of scenarios and other diverse visions of the future, including the understandings of IPLC, is critical to support policy and management actions today and contribute to sustainable resource management and just outcomes for nature and people. Scenarios of continuation of current trends place biodiversity at risk and have negative implications for water, food, health, climate change and NCP. These scenarios also indicate that the decline in biodiversity will continue unless rapid, integrated and transformative change is undertaken across the nexus. On the other hand, scenarios exploring expansion of nature conservation deliver positive outcomes for all nexus elements when planned in an integrated and just manner and coupled with broader measures such as climate change mitigation, changes in food production, equitable consumption and sustainable management. Consequently, transformative change across the food system is central to unlocking co-benefits for biodiversity, water, nutritional health and climate change. Human-induced climate change is expected to impact the entire nexus, becoming worse over the coming decades. In this respect, scenarios indicate the importance of early climate change mitigation actions, with further delays expected to be more costly and leading to additional trade-offs. In general, scenarios leading to better outcomes for the nexus elements tend to also support achieving globally agreed policy goals such as the SDGs. However, they require flexible and well-functioning institutions, mainstreaming and enforcing environmental and pro-sustainability regulations and facilitating cooperation between countries and societal sectors such as governments, non-governmental organizations and businesses, as well as sustainable consumption and production patterns.

REFERENCES

Abell, R., Allan, J. D., & Lehner, B. (2007). Unlocking the potential of protected areas for freshwaters. *Biological Conservation*, *134*(1), 48–63. https://doi.org/10.1016/j.biocon.2006.08.017

Abell, R., Vigerstol, K., Higgins, J., Kang, S., Karres, N., Lehner, B., Sridhar, A., & Chapin, E. (2019). Freshwater biodiversity conservation through source water protection: Quantifying the potential and addressing the challenges. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *29*(7), 1022–1038. https://doi.org/10.1002/aqc.3091

Adame, M. F., Hermoso, V., Perhans, K., Lovelock, C. E., & Herrera-Silveira, J. A. (2015). Selecting cost-effective areas for restoration of ecosystem services. *Conservation Biology*, *29*(2), 493–502. https://doi.org/10.1111/cobi.12391

Adams, V. M., Álvarez-Romero, J. G., Carwardine, J., Cattarino, L., Hermoso, V., Kennard, M. J., Linke, S., Pressey, R. L., & Stoeckl, N. (2014). Planning Across Freshwater and Terrestrial Realms: Cobenefits and Tradeoffs Between Conservation Actions: Cross-realm systematic planning. *Conservation Letters*, *7*(5), 425–440. https://doi.org/10.1111/conl.12080

Alexander, P., Reddy, A., Brown, C., Henry, R. C., & Rounsevell, M. D. A. (2019). Transforming agricultural land use through marginal gains in the food system. *Global Environmental Change*, *57*, 101932. https://doi.org/10.1016/j.gloenvcha.2019.101932

Alexandratos, N., Bruinsma, J., Alexandratos, N., & Bruinsma, J. (2012). *World agriculture towards 2030/2050: The 2012 revision*. FAO. https://ageconsearch.umn.edu/record/288998

Alkama, R., & Cescatti, A. (2016). Biophysical climate impacts of recent changes in global forest cover. *Science*, *351*(6273), 600–604. https://doi.org/10.1126/science.aac8083

Alkemade, R., Reid, R. S., van den Berg, M., de Leeuw, J., & Jeuken, M. (2013). Assessing the impacts of livestock production on biodiversity in rangeland ecosystems. *Proceedings of the National Academy of Sciences*, *110*(52), 20900–20905. https://doi.org/10.1073/pnas.1011013108

Allen, M. R., de Coninck, H., Dube, O. P., Hoegh-Guldberg, O., Kejun Jiang, D. J., Revi, A., Rogelj, J., Roy, J., Shindell, D., Solecki, W., Taylor, Michael, Tschakert, Petra, Waisman, Henri, Abdul Halim, Sharina, Antwi-Agyei, Philip, Aragón-Durand, Fernando, Babiker, Mustafa, Bertoldi, Paolo, Bindi, Marco, … Zickfeld, Kirsten. (2019). *Technical Summary: Global warming of 1.5 C. An IPCC Special Report on the impacts of global warming of 1.5 C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. https://doi.org/10.1017/9781009157940.002

Anderson, D. M., Cembella, A. D., & Hallegraeff, G. M. (2012). Progress in understanding harmful algal blooms: Paradigm shifts and new technologies for research, monitoring, and management. *Annual Review of Marine Science*, *4*, 143–176. https://doi.org/10.1146/annurev-marine-120308-081121

Arkema, K. K., Griffin, R., Maldonado, S., Silver, J., Suckale, J., & Guerry, A. D. (2017). Linking social, ecological, and physical science to advance natural and nature-based protection for coastal communities. *Annals of the New York Academy of Sciences*, *1399*(1), 5–26. https://doi.org/10.1111/nyas.13322

Armitage, D., Berkes, F., Dale, A., Kocho-Schellenberg, E., & Patton, E. (2011). Co-management and the co-production of knowledge: Learning to adapt in Canada's Arctic. *Global Environmental Change*, *21*(3), 995–1004. https://doi.org/10.1016/j.gloenvcha.2011.04.006

Armstrong McKay, D. I., Staal, A., Abrams, J. F., Winkelmann, R., Sakschewski, B., Loriani, S., Fetzer, I., Cornell, S. E., Rockström, J., & Lenton, T. M. (2022). Exceeding 1.5°C global warming could trigger multiple climate tipping points. *Science*, *377*(6611), eabn7950. https://doi.org/10.1126/science.abn7950

Arneth, A., Leadley, P., Claudet, J., Coll, M., Rondinini, C., Rounsevell, M. D. A., Shin, Y., Alexander, P., & Fuchs, R. (2023). Making protected areas effective for biodiversity, climate and food. *Global Change Biology*, *29*(14), 3883–3894. https://doi.org/10.1111/gcb.16664

Arneth, A., Olsson, L., Cowie, A., Erb, K.-H., Hurlbert, M., Kurz, W. A., Mirzabaev, A., & Rounsevell, M. D. A. (2021). Restoring Degraded Lands. *Annual Review of Environment and Resources*, *46*(1), 569–599. https://doi.org/10.1146/annurev-environ-012320-054809

Arneth, A., Shin, Y.-J., Leadley, P., Rondinini, C., Bukvareva, E., Kolb, M., Midgley, G. F., Oberdorff, T., Palomo, I., & Saito, O. (2020). Post-2020 biodiversity targets need to embrace climate change. *Proceedings of the National Academy of Sciences*, *117*(49), 30882–30891. https://doi.org/10.1073/pnas.2009584117

Arthington, A. H., Tickner, D., McClain, M. E., Acreman, M. C., Anderson, E. P., Babu, S., Dickens, C. W. S., Horne, A. C., Kaushal, N., Monk, W. A., O'Brien, G. C., Olden, J. D., Opperman, J. J., Owusu, A. G., LeRoy Poff, N., Richter, B. D., Salinas-Rodríguez, S. A., Shamboko Mbale, B., Tharme, R. E., & Yarnell, S. M. (2023). Accelerating environmental flow implementation to bend the curve of global freshwater biodiversity loss. *Environmental Reviews*, er-2022-0126. https://doi.org/10.1139/er-2022-0126

Arute, F., Arya, K., Babbush, R., Bacon, D., Bardin, J. C., Barends, R., Biswas, R., Boixo, S., Brandao, F. G. S. L., Buell, D. A., Burkett, B., Chen, Y., Chen, Z., Chiaro, B., Collins, R., Courtney, W., Dunsworth, A., Farhi, E., Foxen, B., … Martinis, J. M. (2019). Quantum supremacy using a programmable superconducting processor. *Nature*, *574*(7779), 505–510. https://doi.org/10.1038/s41586-019-1666-5

Atsali, S. S. (2020). Community-based access and benefit-sharing platform and its role in biodiversity, culture and intellectual property rights. *IOP Conference Series: Earth and Environmental Science*, *482*(1). Scopus. https://doi.org/10.1088/1755-1315/482/1/012009

Ba, W., Du, P., Liu, T., Bao, A., Chen, X., Liu, J., & Qin, C. (2020). Impacts of climate change and agricultural activities on water quality in the Lower Kaidu River Basin, China. *Journal of Geographical Sciences*, *30*(1), 164–176. Scopus. https://doi.org/10.1007/s11442-020-1721-z

Babcock, R. C., Bustamante, R. H., Fulton, E. A., Fulton, D. J., Haywood, M. D. E., Hobday, A. J., Kenyon, R., Matear, R. J., Plagányi, E. E., Richardson, A.

J., & Vanderklift, M. A. (2019). Severe Continental-Scale Impacts of Climate Change Are Happening Now: Extreme Climate Events Impact Marine Habitat Forming Communities Along 45 per cent of Australia's Coast. *Frontiers in Marine Science*, *6*. https://www.frontiersin.org/articles/10.3389/fmars.2019.00411

Bahar, N. H. A., Lo, M., Sanjaya, M., Van Vianen, J., Alexander, P., Ickowitz, A., & Sunderland, T. (2020). Meeting the food security challenge for nine billion people in 2050: What impact on forests? *Global Environmental Change*, *62*, 102056. https://doi.org/10.1016/j.gloenvcha.2020.102056

Baker, R. E., Mahmud, A. S., Miller, I. F., Rajeev, M., Rasambainarivo, F., Rice, B. L., Takahashi, S., Tatem, A. J., Wagner, C. E., Wang, L.-F., Wesolowski, A., & Metcalf, C. J. E. (2022). Infectious disease in an era of global change. *Nature Reviews Microbiology*, *20*(4), 193–205. https://doi.org/10.1038/s41579-021-00639-z

Balemie, K., & Singh, R. K. (2012). Conservation of Socioculturally Important Local Crop Biodiversity in the Oromia Region of Ethiopia: A Case Study. *Environmental Management*, *50*(3), 352–364. https://doi.org/10.1007/s00267-012-9883-9

Barnes, M. D., Glew, L., Wyborn, C., & Craigie, I. D. (2018). Prevent perverse outcomes from global protected area policy. *Nature Ecology & Evolution*, *2*(5), 759–762. https://doi.org/10.1038/s41559-018-0501-y

Bartlett, H., Holmes, M. A., Petrovan, S. O., Williams, D. R., Wood, J. L. N., & Balmford, A. (2022). Understanding the relative risks of zoonosis emergence under contrasting approaches to meeting livestock product demand. *Royal Society Open Science*, *9*(6), 211573. https://doi.org/10.1098/rsos.211573

Basnet, S., Wood, A., Röös, E., Jansson, T., Fetzer, I., & Gordon, L. (2023a). Organic agriculture in a low-emission world: Exploring combined measures to deliver a sustainable food system in Sweden. *Sustainability Science*, *18*(1), 501–519. https://doi.org/10.1007/s11625-022-01279-9

Basnet, S., Wood, A., Röös, E., Jansson, T., Fetzer, I., & Gordon, L. (2023b). Organic agriculture in a low-emission world: Exploring combined measures to deliver a sustainable food system in Sweden. *Sustainability Science*, *18*(1), 501–519. https://doi.org/10.1007/s11625-022-01279-9

Bates, A. E., Primack, R. B., Biggar, B. S., Bird, T. J., Clinton, M. E., Command, R. J., Richards, C., Shellard, M., Geraldi, N. R., Vergara, V., Acevedo-Charry, O., Colón-Piñeiro, Z., Ocampo, D., Ocampo-Peñuela, N., Sánchez-Clavijo, L. M., Adamescu, C. M., Cheval, S., Racoviceanu, T., Adams, M. D., … Duarte, C. M. (2021). Global COVID-19 lockdown highlights humans as both threats and custodians of the environment. *Biological Conservation*, *263*, 109175. https://doi.org/10.1016/j.biocon.2021.109175

Bauer, B., Gustafsson, B. G., Hyytiäinen, K., Meier, H. E. M., Müller-Karulis, B., Saraiva, S., & Tomczak, M. T. (2019). Food web and fisheries in the future Baltic Sea. *Ambio*, *48*(11), 1337–1349. https://doi.org/10.1007/s13280-019-01229-3

Bauer, N., Rose, S. K., Fujimori, S., Van Vuuren, D. P., Weyant, J., Wise, M., Cui, Y., Daioglou, V., Gidden, M. J., Kato, E., Kitous, A., Leblanc, F., Sands, R., Sano, F., Strefler, J., Tsutsui, J., Bibas, R., Fricko, O., Hasegawa, T., … Muratori, M. (2020). Global energy sector emission reductions and bioenergy use: Overview of the bioenergy demand phase of the EMF-33 model comparison. *Climatic Change*, *163*(3), 1553–1568. https://doi.org/10.1007/s10584-018-2226-y

Bayraktarov, E., Saunders, M. I., Abdullah, S., Mills, M., Beher, J., Possingham, H. P., Mumby, P. J., & Lovelock, C. E. (2016). The cost and feasibility of marine coastal restoration. *Ecological Applications*, *26*(4), 1055–1074. https://doi.org/10.1890/15-1077

Beaumont, L. J., Pitman, A., Perkins, S., Zimmermann, N. E., Yoccoz, N. G., & Thuiller, W. (2011). Impacts of climate change on the world's most exceptional ecoregions. *Proceedings of the National Academy of Sciences*, *108*(6), 2306–2311. https://doi.org/10.1073/pnas.1007217108

Beck, M. B., Gyawali, D., & Thompson, M. (2019). Societal Drivers of Food and Water Systems 2: Applying Plural Rationality to Some Wicked Problems. In *The Oxford Handbook of Food, Water and Society*. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780190669799.013.62

Begum, R. A., Lempert, R., Ali, E., Benjaminsen, T. A., Bernauer, T., Cramer, W., Cui, X., Mach, K., Nagy, G., Stenseth, N. C., Sukumar, R., & Wester, P. (2022). Point of Departure and Key Concepts. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 121–196). Cambridge University Press. https://doi.org/10.1017/9781009325844.003

Belletti, B., Garcia de Leaniz, C., Jones, J., Bizzi, S., Börger, L., Segura, G., Castelletti, A., van de Bund, W., Aarestrup, K., Barry, J., Belka, K., Berkhuysen, A., Birnie-Gauvin, K., Bussettini, M., Carolli, M., Consuegra, S., Dopico, E., Feierfeil, T., Fernández, S., … Zalewski, M. (2020). More than one million barriers fragment Europe's rivers. *Nature*, *588*(7838), 436–441. https://doi.org/10.1038/s41586-020-3005-2

Bergström, U., Sundblad, G., Downie, A.-L., Snickars, M., Boström, C., & Lindegarth, M. (2013). Evaluating eutrophication management scenarios in the Baltic Sea using species distribution modelling. *Journal of Applied Ecology*, *50*(3), 680–690. https://doi.org/10.1111/1365-2664.12083

Bertram, C., Luderer, G., Popp, A., Minx, J. C., Lamb, W. F., Stevanović, M., Humpenöder, F., Giannousakis, A., & Kriegler, E. (2018). Targeted policies can compensate most of the increased sustainability risks in 1.5 °C mitigation scenarios. *Environmental Research Letters*, *13*(6), 064038. https://doi.org/10.1088/1748-9326/aac3ec

Bianchi, D., Carozza, D. A., Galbraith, E. D., Guiet, J., & DeVries, T. (2021). Estimating global biomass and biogeochemical cycling of marine fish with and without fishing. *Science Advances*, *7*(41), eabd7554. https://doi.org/10.1126/sciadv.abd7554

Bijl, D. L., Bogaart, P. W., Dekker, S. C., Stehfest, E., De Vries, B. J. M., & Van Vuuren, D. P. (2017). A physically-based model of long-term food demand. *Global Environmental Change*, *45*, 47–62. https://doi.org/10.1016/j.gloenvcha.2017.04.003

BIONEXT. (2023). *BIONEXT Project*. BIONEXT Project. https://www.bionext-project.eu

Boelee, E., Janse, J., Le Gal, A., Kok, M., Alkemade, R., & Ligtvoet, W. (2017). Overcoming water challenges through nature-based solutions. *Water Policy*, *19*(5), 820–836. https://doi.org/10.2166/wp.2017.105

Boerlijst, S. P., Johnston, E. S., Ummels, A., Krol, L., Boelee, E., Van Bodegom, P. M., & Schrama, M. J. J. (2023). Biting the hand that feeds: Anthropogenic drivers interactively make mosquitoes thrive. *Science of The Total Environment*, *858*, 159716. https://doi.org/10.1016/j.scitotenv.2022.159716

Bonsch, M., Humpenöder, F., Popp, A., Bodirsky, B., Dietrich, J. P., Rolinski, S., Biewald, A., Lotze-Campen, H., Weindl, I., Gerten, D., & Stevanovic, M. (2016). Trade-offs between land and water requirements for large-scale bioenergy production. *GCB Bioenergy*, *8*(1), 11–24. https://doi.org/10.1111/gcbb.12226

Borma, L. S., Costa, M. H., da Rocha, H. R., Arieira, J., Nascimento, N. C. C., Jaramillo-Giraldo, C., Ambrosio, G., Carneiro, R. G., Venzon, M., Neto, A. F., van der Hoff, R., Oliveira, B. F. A., Rajão, R., & Nobre, C. A. (2022). Beyond Carbon: The Contributions of South American Tropical Humid and Subhumid Forests to Ecosystem Services. *Reviews of Geophysics*, *60*(4), e2021RG000766. https://doi.org/10.1029/2021RG000766

Boyce, D. G., Lotze, H. K., Tittensor, D. P., Carozza, D. A., & Worm, B. (2020). Future ocean biomass losses may widen socioeconomic equity gaps. *Nature Communications*, *11*(1), 2235. https://doi.org/10.1038/s41467-020-15708-9

Boyce, D. G., Tittensor, D. P., Garilao, C., Henson, S., Kaschner, K., Kesner-Reyes, K., Pigot, A., Reyes, R. B., Reygondeau, G., Schleit, K. E., Shackell, N. L., Sorongon-Yap, P., & Worm, B. (2022). A climate risk index for marine life. *Nature Climate Change*, *12*(9), Article 9. https://doi.org/10.1038/s41558-022-01437-y

Boyd, P. W., Bach, L. T., Hurd, C. L., Paine, E., Raven, J. A., & Tamsitt, V. (2022). Potential negative effects of ocean afforestation on offshore ecosystems. *Nature Ecology & Evolution*, *6*(6), Article 6. https://doi.org/10.1038/s41559-022-01722-1

Brito-Morales, I., Schoeman, D. S., Everett, J. D., Klein, C. J., Dunn, D. C., García Molinos, J., Burrows, M. T., Buenafe, K. C. V., Dominguez, R. M., Possingham, H. P., & Richardson, A. J. (2022). Towards climate-smart, three-dimensional protected areas for biodiversity conservation in the high seas. *Nature Climate Change*, *12*(4), 402–407. https://doi.org/10.1038/s41558-022-01323-7

Britton, J. R., Lynch, A. J., Bardal, H., Bradbeer, S. J., Coetzee, J. A., Coughlan, N. E., Dalu, T., Tricarico, E., Gallardo, B., Lintermans, M., Lucy, F., Liu, C., Olden, J. D., Raghavan, R., & Pritchard, E. G. (2023). Preventing and controlling nonnative species invasions to bend the curve of global freshwater biodiversity loss. *Environmental Reviews*, *31*(2), 310–326. https://doi.org/10.1139/er-2022-0103

Brown, C., Seo, B., Alexander, P., Burton, V., Chacón-Montalván, E., Dunford, R., Merkle, M., Harrison, P. A., Prestele, R., Robinson, E. L., & Rounsevell, M. D. A. (2022). *Agent-based modelling of alternative futures in the British land use system*. Environmental Sciences. https://doi.org/10.1002/essoar.10511449.1

Bryndum-Buchholz, A., Blanchard, J., Coll, M., Du Pontavice, H., Everett, J., Guiet, J., Heneghan, R., Maury, O., Novaglio, C., Palacios Abrantes, J., Petrik, C., Tittensor, D., & Lotze, H. (2023). Applying ensemble ecosystem model projections to future-proof marine conservation planning in the Northwest Atlantic Ocean. *FACETS*, *8*, 1–16. https://doi.org/10.1139/facets-2023-0024

Bryndum-Buchholz, A., Boerder, K., Stanley, R., Hurley, I., Boyce, D., Dunmall, K., Hunter, K., Lotze, H., Shackell, N., Worm, B., & Tittensor, D. (2022). A climate-resilient marine conservation network for Canada. *FACETS*, *7*, 571–590. https://doi.org/10.1139/facets-2021-0122

Bryndum-Buchholz, A., Prentice, F., Tittensor, D. P., Blanchard, J. L., Cheung, W. W. L., Christensen, V., Galbraith, E. D., Maury, O., & Lotze, H. K. (2020). Differing marine animal biomass shifts under 21st century climate change between Canada's three oceans. *FACETS*, *5*(1), 105–122. https://doi.org/10.1139/facets-2019-0035

Budiharta, S., Meijaard, E., Gaveau, D. L. A., Struebig, M. J., Wilting, A., Kramer-Schadt, S., Niedballa, J., Raes, N., Maron, M., & Wilson, K. A. (2018). Restoration to offset the impacts of developments at a landscape scale reveals opportunities, challenges and tough choices. *Global Environmental Change*, *52*, 152–161. https://doi.org/10.1016/j.gloenvcha.2018.07.008

Budiharta, S., Meijaard, E., Wells, J. A., Abram, N. K., & Wilson, K. A. (2016). Enhancing feasibility: Incorporating a socio-ecological systems framework into restoration planning. *Environmental Science & Policy*, *64*, 83–92. https://doi.org/10.1016/j.envsci.2016.06.014

Burek, P., Satoh, Y., Fischer, G., Kahil, M. T., Scherzer, A., Tramberend, S., Nava, L. F., Wada, Y., Eisner, S., Flörke, M., Hanasaki, N., Magnuszewski, P., Cosgrove, B., & Wiberg, D. (2016). *Water Futures and Solution—Fast Track Initiative (Final Report)* [Monograph]. https://pure.iiasa.ac.at/13008

Burgess, M. G., Becker, S. L., Langendorf, R. E., Fredston, A., & Brooks, C. M. (2023). Climate change scenarios in fisheries and aquatic conservation research. *ICES Journal of Marine Science*, *80*(5), 1163–1178. https://doi.org/10.1093/icesjms/fsad045

Byers, E., Gidden, M., Leclère, D., Balkovic, J., Burek, P., Ebi, K., Greve, P., Grey, D., Havlik, P., Hillers, A., Johnson, N., Kahil, T., Krey, V., Langan, S., Nakicenovic, N., Novak, R., Obersteiner, M., Pachauri, S., Palazzo, A., … Riahi, K. (2018). Global exposure and vulnerability to multi-sector development and climate change hotspots. *Environmental Research Letters*, *13*(5), 055012. https://doi.org/10.1088/1748-9326/aabf45

Calvin, K., Cowie, A., Berndes, G., Arneth, A., Cherubini, F., Portugal-Pereira, J., Grassi, G., House, J., Johnson, F. X., Popp, A., Rounsevell, M., Slade, R., & Smith, P. (2021). Bioenergy for climate change mitigation: Scale and sustainability. *GCB Bioenergy*, *13*(9), 1346–1371. https://doi.org/10.1111/gcbb.12863

Candy, S., Turner, G., Larsen, K., Wingrove, K., Steenkamp, J., Friel, S., & Lawrence, M. (2019). Modelling the Food Availability and Environmental Impacts of a Shift Towards Consumption of Healthy Dietary Patterns in Australia. *Sustainability*, *11*(24), 7124. https://doi.org/10.3390/su11247124

Capitani, C., Garedew, W., Mitiku, A., Berecha, G., Hailu, B. T., Heiskanen, J., Hurskainen, P., Platts, P. J., Siljander, M., Pinard, F., Johansson, T., & Marchant, R. (2019). Views from two mountains: Exploring climate change impacts on traditional farming communities of Eastern Africa highlands through participatory scenarios. *Sustainability Science*, *14*(1), 191–203. https://doi.org/10.1007/s11625-018-0622-x

Caretta, M. A., Mukherji, A., Arfanuzzaman, M., Betts, R. A., Gelfan, A., Hirabayashi, T. K., Lissner, T., Liu, J., Lopez Gunn, E., Morgan, R., Mwanga, S., & Supratid, S. (2022). Water. In Pörtner, H.-O., Roberts, D. C., Tignor, M., Poloczanska, E. S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A., & Rama, B. (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 551–712). Cambridge University Press. https://doi.org/10.1017/9781009325844.006

Carlson, C. J., Albery, G. F., Merow, C., Trisos, C. H., Zipfel, C. M., Eskew, E. A., Olival, K. J., Ross, N., & Bansal, S. (2022). Climate change increases cross-species viral transmission risk. *Nature*, *607*(7919), 555–562. https://doi.org/10.1038/s41586-022-04788-w

Cartes, J. E., Maynou, F., & Fanelli, E. (2011). Nile damming as plausible cause of extinction and drop in abundance of deep-sea shrimp in the western Mediterranean over broad spatial scales. *Progress in Oceanography*, *91*(3), 286–294. https://doi.org/10.1016/j.pocean.2011.01.004

Cassidy, E. S., West, P. C., Gerber, J. S., & Foley, J. A. (2013). Redefining agricultural yields: From tonnes to people nourished per hectare. *Environmental Research Letters*, *8*(3), 034015. https://doi.org/10.1088/1748-9326/8/3/034015

Ceglar, A., Zampieri, M., Toreti, A., & Dentener, F. (2019). Observed Northward Migration of Agro-Climate Zones in Europe Will Further Accelerate Under Climate Change. *Earth's Future*, *7*(9), 1088–1101. https://doi.org/10.1029/2019EF001178

Chan, K. M. A., Boyd, D. R., Gould, R. K., Jetzkowitz, J., Liu, J., Muraca, B., Naidoo, R., Olmsted, P., Satterfield, T., Selomane, O., Singh, G. G., Sumaila, R., Ngo, H. T., Boedhihartono, A. K., Agard, J., de Aguiar, A. P. D., Armenteras, D., Balint, L., Barrington-Leigh, C., … Brondízio, E. S. (2020). Levers and leverage points for pathways to sustainability. *People and Nature*, *2*(3), 693–717. https://doi.org/10.1002/pan3.10124

Chaplin-Kramer, R., Brauman, K. A., Cavender-Bares, J., Díaz, S., Duarte, G. T., Enquist, B. J., Garibaldi, L. A., Geldmann, J., Halpern, B. S., Hertel, T. W., Khoury, C. K., Krieger, J. M., Lavorel, S., Mueller, T., Neugarten, R. A., Pinto-Ledezma, J., Polasky, S., Purvis, A., Reyes-García, V., … Zafra-Calvo, N. (2022). Conservation needs to integrate knowledge across scales. *Nature Ecology & Evolution*, *6*(2), 118–119. https://doi.org/10.1038/s41559-021-01605-x

Chapman, M., Jung, M., Leclère, D., Boettiger, C., D.Augustynczik, A. L., Gusti, M., Ringwald, L., & Visconti, P. (2023). *Meeting European conservation and restoration targets under future land-use demands* [Preprint]. Open Science Framework. https://doi.org/10.31219/osf.io/ynqfx

Chatzimpiros, P., & Harchaoui, S. (2023). Sevenfold variation in global feeding capacity depends on diets, land use and nitrogen management. *Nature Food*, *4*(5), Article 5. https://doi.org/10.1038/s43016-023-00741-w

Chausson, A., Turner, B., Seddon, D., Chabaneix, N., Girardin, C. A. J., Kapos, V., Key, I., Roe, D., Smith, A., Woroniecki, S., & Seddon, N. (2020). Mapping the effectiveness of nature-based solutions for climate change adaptation. *Global Change Biology*, *26*(11), 6134–6155. https://doi.org/10.1111/gcb.15310

Chen, L., Wang, J., Beiyuan, J., Guo, X., Wu, H., & Fang, L. (2022). Environmental and health risk assessment of potentially toxic trace elements in soils near uranium (U) mines: A global meta-analysis. *Science of the Total Environment*, *816*, 151556. https://doi.org/10.1016/j.scitotenv.2021.151556

Chivenge, P., Mabhaudhi, T., Modi, A., & Mafongoya, P. (2015). The Potential Role of Neglected and Underutilised Crop Species as Future Crops under Water Scarce Conditions in Sub-Saharan Africa. *International Journal of Environmental Research and Public Health*, *12*(6), 5685–5711. https://doi.org/10.3390/ijerph120605685

Clark, M. A., Domingo, N. G. G., Colgan, K., Thakrar, S. K., Tilman, D., Lynch, J., Azevedo, I. L., & Hill, J. D. (2020). Global food system emissions could preclude achieving the 1.5° and 2°C climate change targets. *Science*, *370*(6517), 705–708. https://doi.org/10.1126/science.aba7357

Cochran, P., Huntington, O. H., Pungowiyi, C., Tom, S., Chapin, F. S., Huntington, H. P., Maynard, N. G., & Trainor, S. F. (2013). Indigenous frameworks for observing and responding to climate change in Alaska. *Climate Change and Indigenous Peoples in the United States*, 49–59. https://doi.org/10.1007/978-3-319-05266-3_5

Coll, M., Steenbeek, J., Pennino, M. G., Buszowski, J., Kaschner, K., Lotze, H. K., Rousseau, Y., Tittensor, D. P., Walters, C., Watson, R. A., & Christensen, V. (2020). Advancing Global Ecological Modeling Capabilities to Simulate Future Trajectories of Change in Marine Ecosystems. *Frontiers in Marine Science*, *7*, 567877. https://doi.org/10.3389/fmars.2020.567877

Colón-González, F. J., Sewe, M. O., Tompkins, A. M., Sjödin, H., Casallas, A., Rocklöv, J., Caminade, C., & Lowe, R. (2021). Projecting the risk of mosquito-borne diseases in a warmer and more populated world: A multi-model, multi-scenario intercomparison modelling study. *The Lancet Planetary Health*, *5*(7), e404–e414. https://doi.org/10.1016/S2542-5196(21)00132-7

Combes, M., Vaz, S., Grehan, A., Morato, T., Arnaud-Haond, S., Dominguez-Carrió, C., Fox, A., González-Irusta, J. M., Johnson, D., Callery, O., Davies, A., Fauconnet, L., Kenchington, E., Orejas, C., Roberts, J. M., Taranto, G., & Menot, L. (2021). Systematic Conservation Planning at an Ocean Basin Scale: Identifying a Viable Network of Deep-Sea Protected Areas in the North Atlantic and the Mediterranean. *Frontiers in Marine Science*, *8*. https://doi.org/10.3389/fmars.2021.611358

Conley, D. J., Björck, S., Bonsdorff, E., Carstensen, J., Destouni, G., Gustafsson, B. G., Hietanen, S., Kortekaas, M., Kuosa, H., Markus Meier, H., Müller-Karulis, Baerbel, Nordberg, Kjell, Norkko, Alf, Nürnberg, Gertrud, Pitkänen, Heikki, Rabalais, Nancy N., Rosenberg, Rutger, Savchuk, Oleg P., Slomp, Caroline P., … Zillén, Lovisa. (2009). Hypoxia-related processes in the Baltic Sea. *Environmental Science & Technology*, *43*(10), 3412–3420. https://doi.org/10.1021/es802762a

Corrales, X., Coll, M., Ofir, E., Heymans, J. J., Steenbeek, J., Goren, M., Edelist, D., & Gal, G. (2018). Future scenarios of marine resources and ecosystem conditions in the Eastern Mediterranean under the impacts of fishing, alien species and sea warming. *Scientific Reports*, *8*(1), 14284. https://doi.org/10.1038/s41598-018-32666-x

Correa, D. F., Beyer, H. L., Possingham, H. P., Thomas-Hall, S. R., & Schenk, P. M. (2017). Biodiversity impacts of bioenergy production: Microalgae vs. first generation biofuels. *Renewable and Sustainable Energy Reviews*, *74*, 1131–1146. https://doi.org/10.1016/j.rser.2017.02.068

Costa, W., Scarabello, M., Soterroni, A., & Ramos, F. (2020). *Pathways to Sustainable Land-Use and Food Systems in Brazil by 2050* (pp. 130–160). International Institute for Applied Systems Analysis (IIASA) and Sustainable Development Solutions Network (SDSN). https://doi.org/10.22022/ESM/12-2020.16896

Curran, M., Hellweg, S., & Beck, J. (2014). Is there any empirical support for biodiversity offset policy? *Ecological Applications*, *24*(4), 617–632. https://doi.org/10.1890/13-0243.1

Dasgupta, P., & Shakya, B. (2023). Ecosystem services as systemic enablers for transformation in the Hindu Kush Himalaya: An analytical synthesis. *Regional Environmental Change*, *23*(1), 39. https://doi.org/10.1007/s10113-022-02022-x

Davies, K. P., Gibney, E. R., & O'Sullivan, A. M. (2023). Moving towards more sustainable diets: Is there potential for a personalised approach in practice? *Journal of Human Nutrition and Dietetics*, *36*(6), 2256–2267. https://doi.org/10.1111/jhn.13218

De Bruin, S. P., Van Vliet, J., Lehmann, I., & Verburg, P. (2023). Perceptions of equity in conservation scenarios: Half Earth and Sharing the Planet. *Environmental Science & Policy*, *144*, 124–136. https://doi.org/10.1016/j.envsci.2023.03.015

de Jong, J., Akselsson, C., Egnell, G., Löfgren, S., & Olsson, B. A. (2017). Realizing the energy potential of forest biomass in Sweden – How much is environmentally sustainable? *Forest Ecology and Management*, *383*, 3–16. https://doi.org/10.1016/j.foreco.2016.06.028

DeAngelo, J., Saenz, B. T., Arzeno-Soltero, I. B., Frieder, C. A., Long, M. C., Hamman, J., Davis, K. A., & Davis, S. J. (2023a). Author Correction: Economic and biophysical limits to seaweed farming for climate change mitigation. *Nature Plants*, *9*(4), Article 4. https://doi.org/10.1038/s41477-023-01393-1

DeAngelo, J., Saenz, B. T., Arzeno-Soltero, I. B., Frieder, C. A., Long, M. C., Hamman, J., Davis, K. A., & Davis, S. J. (2023b). Economic and biophysical limits to seaweed farming for climate change mitigation. *Nature Plants*, *9*(1), Article 1. https://doi.org/10.1038/s41477-022-01305-9

Delevaux, J. M. S., Jupiter, S. D., Stamoulis, K. A., Bremer, L. L., Wenger, A. S., Dacks, R., Garrod, P., Falinski, K. A., & Ticktin, T. (2018). Scenario planning with linked land-sea models inform where forest conservation actions will promote coral reef resilience. *Scientific Reports*, *8*(1), 12465. https://doi.org/10.1038/s41598-018-29951-0

Díaz, S., Settele, J., Brondízio, E. S., Ngo, H. T., Agard, J., Arneth, A., Balvanera, P., Brauman, K. A., Butchart, S. H. M., Chan, K. M. A., Garibaldi, L. A., Ichii, K., Liu, J., Subramanian, S. M., Midgley, G. F., Miloslavich, P., Molnár, Z., Obura, D., Pfaff, A., … Zayas, C. N. (2019). Pervasive human-driven decline of life on Earth points to the need for transformative change. *Science*, *366*(6471), eaax3100. https://doi.org/10.1126/science.aax3100

Diggon, S., Bones, J., Short, C. J., Smith, J. L., Dickinson, M., Wozniak, K., Topelko, K., & Pawluk, K. A. (2022). The Marine Plan Partnership for the North Pacific Coast – MaPP: A collaborative and co-led marine planning process in British Columbia. *Marine Policy*, *142*, 104065. https://doi.org/10.1016/j.marpol.2020.104065

Diprose, G., Greenaway, A., & Moorhouse, B. (2022). Making Visible More Diverse Nature Futures through Citizen Science. *Citizen Science: Theory and Practice*, *7*(1), 6. https://doi.org/10.5334/cstp.442

Doelman, J. C., Beier, F. D., Stehfest, E., Bodirsky, B. L., Beusen, A. H. W., Humpenöder, F., Mishra, A., Popp, A., van Vuuren, D. P., de Vos, L., Weindl, I., van Zeist, W.-J., & Kram, T. (2022). Quantifying synergies and trade-offs in the global water-land-food-climate nexus using a multi-model scenario approach. *Environmental Research Letters*, *17*(4), 045004. https://doi.org/10.1088/1748-9326/ac5766

Doelman, J. C., Verhagen, W., Stehfest, E., & Van Vuuren, D. P. (2023). The role of peatland degradation, protection and restoration for climate change mitigation in the SSP scenarios. *Environmental Research: Climate*, *2*(3), 035002. https://doi.org/10.1088/2752-5295/acd5f4

Donati, G. F. A., Bolliger, J., Psomas, A., Maurer, M., & Bach, P. M. (2022). Reconciling cities with nature: Identifying local Blue-Green Infrastructure interventions for regional biodiversity enhancement. *Journal of Environmental Management*, *316*, 115254. https://doi.org/10.1016/j.jenvman.2022.115254

Duarte, C. M., Agusti, S., Barbier, E., Britten, G. L., Castilla, J. C., Gattuso, J.-P., Fulweiler, R. W., Hughes, T. P., Knowlton, N., Lovelock, C. E., Lotze, H. K., Predragovic, M., Poloczanska, E., Roberts, C., & Worm, B. (2020). Rebuilding marine life. *Nature*, *580*(7801), Article 7801. https://doi.org/10.1038/s41586-020-2146-7

Duarte, C. M., Bruhn, A., & Krause-Jensen, D. (2022). A seaweed aquaculture imperative to meet global sustainability targets. *Nature Sustainability*, *5*(3), Article 3. https://doi.org/10.1038/s41893-021-00773-9

Duarte, C. M., Wu, J., Xiao, X., Bruhn, A., & Krause-Jensen, D. (2017). Can Seaweed Farming Play a Role in Climate Change Mitigation and Adaptation? *Frontiers in Marine Science*, *4*. https://doi.org/10.3389/fmars.2017.00100

Ducharne, A., Baubion, C., Beaudoin, N., Benoit, M., Billen, G., Brisson, N., Garnier, J., Kieken, H., Lebonvallet, S., Ledoux, E., Mary, B., Mignolet, C., Poux, X., Sauboua, E., Schott, C., Théry, S., & Viennot, P. (2007). Long term prospective of the Seine River system: Confronting climatic and direct anthropogenic changes. *Science of the Total Environment*, *375*(1–3), 292–311. https://doi.org/10.1016/j.scitotenv.2006.12.011

Dunford, R., Harrison, P. A., & Rounsevell, M. D. A. (2015). Exploring scenario and model uncertainty in cross-sectoral integrated assessment approaches to climate change impacts. *Climatic Change*, *132*(3), 417–432. https://doi.org/10.1007/s10584-014-1211-3

Durán, A. P., Kuiper, J. J., Aguiar, A. P. D., Cheung, W. W. L., Diaw, M. C., Halouani, G., Hashimoto, S., Gasalla, M. A., Peterson, G. D., Schoolenberg, M. A., Abbasov, R., Acosta, L. A., Armenteras, D., Davila, F., Denboba, M. A., Harrison, P. A., Harhash, K. A., Karlsson-Vinkhuyzen, S., Kim, H., … Pereira, L. M. (2023). Bringing the Nature Futures Framework to life: Creating a set of illustrative narratives of nature futures. *Sustainability Science*. https://doi.org/10.1007/s11625-023-01316-1

Ehrnsten, E., Norkko, A., Timmermann, K., & Gustafsson, B. G. (2019). Benthic-pelagic coupling in coastal seas–Modelling macrofaunal biomass and carbon processing in response to organic matter supply. *Journal of Marine Systems*, *196*, 36–47. https://doi.org/10.1016/j.jmarsys.2019.04.003

Elmahdi, A., & McFarlane, D. (2009). A decision support system for sustainable groundwater management. Case study: Gnangara sustainability strategy—Western Australia. *WIT Transactions on Ecology and the Environment*, *125*, 327–339. Scopus. https://doi.org/10.2495/WRM090301

Engström, K., Olin, S., Rounsevell, M. D. A., Brogaard, S., van Vuuren, D. P., Alexander, P., Murray-Rust, D., & Arneth, A. (2016). Assessing uncertainties in global cropland futures using a conditional probabilistic modelling framework. *Earth System Dynamics*, *7*(4), 893–915. https://doi.org/10.5194/esd-7-893-2016

FABLE. (2020). *Pathways to Sustainable Land-Use and Food Systems. 2020 Report of the FABLE Consortium.* Laxenburg and Paris: International Institute for Applied Systems Analysis (IIASA) and Sustainable Development Solutions Network (SDSN). https://doi.org/10.22022/ESM/12-2020.16896

FABLE. (2021). *Environmental and agricultural impacts of dietary shifts at global and national scales.* (FABLE Policy Brief July 2021). Sustainable Development Solutions Network. https://irp.cdn-website.com/be6d1d56/files/uploaded/210726_FABLEDietBrief_cor per cent20 per cent281 per cent29.pdf

FABLE. (2022a). *National food and land mitigation pathways for net zero* (FABLE Policy Brief). Sustainable Development Solutions Network (SDSN). https://fableconsortium.org/media/images/Docs/FABLE-Net-Zero-Brief.pdf

FABLE. (2022b). *Pathways for food and land use systems to contribute to global biodiversity targets* (FABLE Policy Brief). Alliance of Biodiversity International and the International Center for Tropical Agriculture & Sustainable Development Solutions Network (SDSN). https://irp.cdn-website.com/be6d1d56/files/uploaded/220324_Biodiversity_Brief_FABLE_S5YznEDrS5i1hDfaRid8.pdf

FABLE. (2023). *Fable Consortium*. Fable Consortium. fableconsortium.org

Falardeau, M., Raudsepp-Hearne, C., & Bennett, E. M. (2019). A novel approach for co-producing positive scenarios that explore agency: Case study from the Canadian Arctic. *Sustainability Science*, *14*(1), 205–220. https://doi.org/10.1007/s11625-018-0620-z

FAO. (2020). *The State of World Fisheries and Aquaculture 2020: Sustainability in action*. FAO. https://doi.org/10.4060/ca9229en

FAO. (2022). *The State of World Fisheries and Aquaculture 2022*. FAO. https://doi.org/10.4060/cc0461en

Fargione, J. E., Bassett, S., Boucher, T., Bridgham, S. D., Conant, R. T., Cook-Patton, S. C., Ellis, P. W., Falcucci, A., Fourqurean, J. W., Gopalakrishna, T., Gu, H., Henderson, B., Hurteau, M. D., Kroeger, K. D., Kroeger, T., Lark, T. J., Leavitt, S. M., Lomax, G., McDonald, R. I., … Griscom, B. W. (2018). Natural climate solutions for the United States. *Science Advances*, *4*(11), eaat1869. https://doi.org/10.1126/sciadv.aat1869

Fastré, C., van Zeist, W.-J., Watson, J. E. M., & Visconti, P. (2021). Integrated spatial planning for biodiversity conservation and food production. *One Earth*, *4*(11), 1635–1644. https://doi.org/10.1016/j.oneear.2021.10.014

Fischer, S., Pluntke, T., Pavlik, D., & Bernhofer, C. (2014). Hydrologic effects of climate change in a sub-basin of the Western Bug River, Western Ukraine. *Environmental Earth Sciences*, *72*(12), 4727–4744. https://doi.org/10.1007/s12665-014-3256-z

Fisher, B., Bradbury, R. B., Andrews, J. E., Ausden, M., Bentham-Green, S., White, S. M., & Gill, J. A. (2011). Impacts of species-led conservation on ecosystem services of wetlands: Understanding co-benefits and tradeoffs. *Biodiversity and Conservation*, *20*(11), 2461–2481. https://doi.org/10.1007/s10531-011-9998-y

Fitton, N., Alexander, P., Arnell, N., Bajzelj, B., Calvin, K., Doelman, J., Gerber, J. S., Havlik, P., Hasegawa, T., Herrero, M., Krisztin, T., Van Meijl, H., Powell, T., Sands, R., Stehfest, E., West, P. C., & Smith, P. (2019). The vulnerabilities of agricultural land and food production to future water scarcity. *Global Environmental Change*, *58*, 101944. https://doi.org/10.1016/j.gloenvcha.2019.101944

Folberth, C., Wood, S. A., Wironen, M., Jung, M., Boucher, T. M., Bossio, D., & Obersteiner, M. (2024). Exploring the potential for nitrogen fertilizer use mitigation with bundles of management interventions. *Environmental Research Letters*, *19*(4), 044027. https://doi.org/10.1088/1748-9326/ad31d8

Forsius, M., Akujärvi, A., Mattsson, T., Holmberg, M., Punttila, P., Posch, M., Liski, J., Repo, A., Virkkala, R., & Vihervaara, P. (2016). Modelling impacts of forest bioenergy use on ecosystem sustainability: Lammi LTER region, southern Finland. *Ecological Indicators*, *65*, 66–75. https://doi.org/10.1016/j.ecolind.2015.11.032

Frank, F., Volante, J., Calamari, N., Peri, P., Chavez, B., Martinez, P., Mosciaro, M., Martin, G., Amaro, I., Guerrero, I., Casellas, K., Zuliani, M., Sirimarco, X., Gaitan, J., Cristeche, E., Barral, M., Villarino, S., Zelarayan, A., & Monjeau, A. (2023). A multi-model approach to explore sustainable food and land use pathways for Argentina. *Sustainability Science*, *18*(1), 347–369. https://doi.org/10.1007/s11625-022-01245-5

Frank, S., Witzke, H.-P., Zimmermann, A., Havlík, P., Ciaian, P., Frank, S., Witzke, H.-P., Zimmermann, A., Havlík, P., & Ciaian, P. (2014). Climate change impacts on European agriculture: A multi model perspective. *Agri-Food and Rural Innovations for Healthier Societies*. European Association of Agricultural Economists (EAAE). 2014 International Congress, August 26-29, 2014, Ljubljana, Slovenia. https://doi.org/10.22004/AG.ECON.183025

Fraschetti, S., McOwen, C., Papa, L., Papadopoulou, N., Bilan, M., Boström, C., Capdevila, P., Carreiro-Silva, M., Carugati, L., Cebrian, E., Coll, M., Dailianis, T., Danovaro, R., De Leo, F., Fiorentino, D., Gagnon, K., Gambi, C., Garrabou, J., Gerovasileiou, V., … Guarnieri, G. (2021). Where Is More Important Than How in Coastal and Marine Ecosystems Restoration. *Frontiers in Marine Science*, *8*. https://doi.org/10.3389/fmars.2021.626843

Frietsch, M., Loos, J., Löhr, K., Sieber, S., & Fischer, J. (2023). Future-proofing ecosystem restoration through enhancing adaptive capacity. *Communications Biology*, *6*(1), Article 1. https://doi.org/10.1038/s42003-023-04736-y

Froehlich, H. E., Gentry, R. R., & Halpern, B. S. (2018). Global change in marine aquaculture production potential under climate change. *Nature Ecology & Evolution*, *2*(11), Article 11. https://doi.org/10.1038/s41559-018-0669-1

Fuad, H. A. H., Winarni, N. L., Mumbunan, S., Supriatna, J., Khasanah, N., Boer, R., Immanuel, G., Anggraeni, L., & Rosita, A. (2020). *"Pathways to Sustainable Land-Use and Food Systems in Indonesia by 2050" In: FABLE 2020, Pathways to Sustainable Land-Use and Food Systems, 2020 Report of the FABLE Consortium.* 386–416. https://doi.org/10.22022/ESM/12-2020.16896

Fuhrman, J., Bergero, C., Weber, M., Monteith, S., Wang, F. M., Clarens, A. F., Doney, S. C., Shobe, W., & McJeon, H. (2023). Diverse carbon dioxide removal approaches could reduce impacts on the energy–water–land system. *Nature Climate Change*. https://doi.org/10.1038/s41558-023-01604-9

Fuhrman, J., McJeon, H., Patel, P., Doney, S. C., Shobe, W. M., & Clarens, A. F. (2020). Food–energy–water implications of negative emissions technologies in a +1.5 °C future. *Nature Climate Change*, *10*(10), Article 10. https://doi.org/10.1038/s41558-020-0876-z

Fujimori, S., Hasegawa, T., Krey, V., Riahi, K., Bertram, C., Bodirsky, B. L., Bosetti, V., Callen, J., Després, J., Doelman, J., Drouet, L., Emmerling, J., Frank, S., Fricko, O., Havlik, P., Humpenöder, F., Koopman, J. F. L., van Meijl, H., Ochi, Y., … van Vuuren, D. (2019). A multi-model assessment of food security implications of climate change mitigation. *Nature Sustainability*, *2*(5), 386–396. https://doi.org/10.1038/s41893-019-0286-2

Fujimori, S., Hasegawa, T., Takahashi, K., Dai, H., Liu, J.-Y., Ohashi, H., Xie, Y., Zhang, Y., Matsui, T., & Hijioka, Y. (2020). Measuring the sustainable development implications of climate change mitigation. *Environmental Research Letters*, *15*(8), 085004. https://doi.org/10.1088/1748-9326/ab9966

Fulton, E. A., Boschetti, F., Sporcic, M., Jones, T., Little, L. R., Dambacher, J. M., Gray, R., Scott, R., & Gorton, R. (2015). A multi-model approach to engaging stakeholder and modellers in complex environmental problems. *Environmental Science & Policy*, *48*, 44–56. https://doi.org/10.1016/j.envsci.2014.12.006

Gann, G. D., McDonald, T., Walder, B., Aronson, J., Nelson, C. R., Jonson, J., Hallett, J. G., Eisenberg, C., Guariguata, M. R., Liu, J., Hua, F., Echeverría, C., Gonzales, E., Shaw, N., Decleer, K., & Dixon, K. W. (2019). International principles and standards for the practice of ecological restoration. Second edition. *Restoration Ecology*, *27*(S1), S1–S46. https://doi.org/10.1111/rec.13035

Gao, S., Schwinger, J., Tjiputra, J., Bethke, I., Hartmann, J., Mayorga, E., & Heinze, C. (2023). Riverine impact on future projections of marine primary production and carbon uptake. *Biogeosciences*, *20*(1), 93–119. https://doi.org/10.5194/bg-20-93-2023

García-Peña, G. E., Rubio, A. V., Mendoza, H., Fernández, M., Milholland, M. T., Aguirre, A. A., Suzán, G., & Zambrana-Torrelio, C. (2021). Land-use change and rodent-borne diseases: Hazards on the shared socioeconomic pathways. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *376*(1837), 20200362. https://doi.org/10.1098/rstb.2020.0362

Gephart, J. A., Henriksson, P. J., Parker, R. W., Shepon, A., Gorospe, K. D., Bergman, K., Eshel, G., Golden, C. D., Halpern, B. S., & Hornborg, S. (2021). Environmental performance of blue foods. *Nature*, *597*(7876), 360–365. https://doi.org/10.1038/s41586-021-03889-2

Gerling, C., Drechsler, M., Keuler, K., Leins, J. A., Radtke, K., Schulz, B., Sturm, A., & Wätzold, F. (2022). Climate–ecological–economic modelling for the cost-effective spatiotemporal allocation of conservation measures in cultural landscapes facing climate change. *Q Open*, *2*(1), qoac004. https://doi.org/10.1093/qopen/qoac004

Giakoumi, S., Hermoso, V., Carvalho, S. B., Markantonatou, V., Dagys, M., Iwamura, T., Probst, W. N., Smith, R. J., Yates, K. L., Almpanidou, V., Novak, T., Ben-Moshe, N., Katsanevakis, S., Claudet, J., Coll, M., Deidun, A., Essl, F., García-Charton, J. A., Jimenez, C., … Vogiatzakis, I. N. (2019). Conserving European biodiversity across realms: GIAKOUMI *et al. Conservation Letters*, *12*(1), e12586. https://doi.org/10.1111/conl.12586

Gibson, L., Lee, T. M., Koh, L. P., Brook, B. W., Gardner, T. A., Barlow, J., Peres, C. A., Bradshaw, C. J. A., Laurance, W. F., Lovejoy, T. E., & Sodhi, N. S. (2014). Correction: Corrigendum: Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature*, *505*(7485), 710–710. https://doi.org/10.1038/nature12933

Gleick, P. H. (2014). Water, Drought, Climate Change, and Conflict in Syria. *Weather, Climate, and Society*, *6*(3), 331–340. https://doi.org/10.1175/WCAS-D-13-00059.1

Glibert, P. M., Icarus Allen, J., Artioli, Y., Beusen, A., Bouwman, L., Harle, J., Holmes, R., & Holt, J. (2014). Vulnerability of coastal ecosystems to changes in harmful algal bloom distribution in response to climate change: Projections based on model analysis. *Global Change Biology*, *20*(12), 3845–3858. https://doi.org/10.1111/gcb.12662

Gomei, M., Steenbeek, J., Coll, M., & Claudet, J. (2021). *30 by 30: Scenarios to recover biodiversity and rebuild fish stocks in the Mediterranean* (pp. 1–29). WWF Mediterranean Marine Initiative. http://hdl.handle.net/10261/248058

González-Abraham, C., Flores-Santana, C., Rodríguez-Ramírez, S., Olguín-Álvarez, M., Flores-Martínez, A., Torres Rojo, J. M., Bocco Verdinelli, G., Fernández Calleros, C. A., & McCord, G. C. (2022). Long-term pathways analysis to assess the feasibility of sustainable land-use and food systems in Mexico. *Sustainability Science*. https://doi.org/10.1007/s11625-022-01243-7

Göpel, J., Schüngel, J., Stuch, B., & Schaldach, R. (2020). Assessing the effects of agricultural intensification on natural habitats and biodiversity in Southern Amazonia. *PLOS ONE*, *15*(11), e0225914. https://doi.org/10.1371/journal.pone.0225914

Government of Canada. (2023). *Tuvaijuittuq Marine Protected Area (MPA)*. Tuvaijuittuq Marine Protected Area (MPA). https://www.dfo-mpo.gc.ca/oceans/mpa-zpm/tuvaijuittuq/index-eng.html

Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., Schlesinger, W. H., Shoch, D., Siikamäki, J. V., Smith, P., Woodbury, P., Zganjar, C., Blackman, A., Campari, J., Conant, R. T., Delgado, C., Elias, P., Gopalakrishna, T., Hamsik, M. R., … Fargione, J. (2017). Natural climate solutions. *Proceedings of the National Academy of Sciences*, *114*(44), 11645–11650. https://doi.org/10.1073/pnas.1710465114

Grossmann, M., & Dietrich, O. (2012). Integrated Economic-Hydrologic Assessment of Water Management Options for Regulated Wetlands Under Conditions of Climate Change: A Case Study from the Spreewald (Germany). *Water Resources Management*, *26*(7), 2081–2108. https://doi.org/10.1007/s11269-012-0005-5

Gurney, G. G., Darling, E. S., Ahmadia, G. N., Agostini, V. N., Ban, N. C., Blythe, J., Claudet, J., Epstein, G., Estradivari, Himes-Cornell, A., Jonas, H. D., Armitage, D., Campbell, S. J., Cox, C., Friedman, W. R., Gill, D., Lestari, P., Mangubhai, S., McLeod, E., … Jupiter, S. D. (2021). Biodiversity needs every tool in the box: Use OECMs. *Nature*, *595*(7869), 646–649. https://doi.org/10.1038/d41586-021-02041-4

Gvein, M. H., Hu, X., Næss, J. S., Watanabe, M. D. B., Cavalett, O., Malbranque, M., Kindermann, G., & Cherubini, F. (2023). Potential of land-based climate change mitigation strategies on abandoned cropland. *Communications Earth & Environment*, *4*(1), 39. https://doi.org/10.1038/s43247-023-00696-7

Hagger, V., Waltham, N. J., & Lovelock, C. E. (2022). Opportunities for coastal wetland restoration for blue carbon with co-benefits for biodiversity, coastal fisheries, and water quality. *Ecosystem Services*, *55*, 101423. https://doi.org/10.1016/j.ecoser.2022.101423

Hallegraeff, G. M. (2010). Ocean Climate Change, Phytoplankton Community Responses, and Harmful Algal Blooms: A Formidable Predictive Challenge1. *Journal of Phycology*, *46*(2), 220–235. https://doi.org/10.1111/j.1529-8817.2010.00815.x

Halpern, B. S., McLeod, K. L., Rosenberg, A. A., & Crowder, L. B. (2008). Managing for cumulative impacts in ecosystem-based management through ocean zoning. *Ocean & Coastal Management*, *51*(3), 203–211. https://doi.org/10.1016/j.ocecoaman.2007.08.002

Hamilton, I., Kennard, H., McGushin, A., Höglund-Isaksson, L., Kiesewetter, G., Lott, M., Milner, J., Purohit, P., Rafaj, P., Sharma, R., Springmann, M., Woodcock, J., & Watts, N. (2021). The public health implications of the Paris Agreement: A modelling study. *The Lancet Planetary Health*, *5*(2), e74–e83. https://doi.org/10.1016/S2542-5196(20)30249-7

Hannah, L., Roehrdanz, P. R., Krishna Bahadur, K. C., Fraser, E. D. G., Donatti, C. I., Saenz, L., Wright, T. M., Hijmans, R. J., Mulligan, M., Berg, A., & van Soesbergen, A. (2020). The environmental consequences of climate-driven agricultural frontiers. *PLoS ONE*, *15*(2). Scopus. https://doi.org/10.1371/journal.pone.0228305

Hannah, L., Roehrdanz, P. R., Marquet, P. A., Enquist, B. J., Midgley, G., Foden, W., Lovett, J. C., Corlett, R. T., Corcoran, D., Butchart, S. H. M., Boyle, B., Feng, X., Maitner, B., Fajardo, J., McGill, B. J., Merow, C., Morueta-Holme, N., Newman, E. A., Park, D. S., … Svenning, J.-C. (2020). 30 per cent land conservation and climate action reduces tropical extinction risk by more than 50 per cent. *Ecography*, *43*(7), 943–953. https://doi.org/10.1111/ecog.05166

Hare, J. A., Morrison, W. E., Nelson, M. W., Stachura, M. M., Teeters, E. J., Griffis, R. B., Alexander, M. A., Scott, J. D., Alade, L., Bell, R. J., Chute, A. S., Curti, K. L., Curtis, T. H., Kircheis, D., Kocik, J. F., Lucey, S. M., McCandless, C. T., Milke, L. M., Richardson, D. E., … Griswold, C. A. (2016). A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf. *PLOS ONE*, *11*(2), e0146756. https://doi.org/10.1371/journal.pone.0146756

Harfoot, M. B. J., Newbold, T., Tittensor, D. P., Emmott, S., Hutton, J., Lyutsarev, V., Smith, M. J., Scharlemann, J. P. W., & Purves, D. W. (2014). Emergent Global Patterns of Ecosystem Structure and Function from a Mechanistic General Ecosystem Model. *PLOS Biology*, *12*(4), e1001841. https://doi.org/10.1371/journal.pbio.1001841

Harmáčková, Z. V., Blättler, L., Aguiar, A. P. D., Daněk, J., Krpec, P., & Vačkářová, D. (2022). Linking multiple values of nature with future impacts: Value-based participatory scenario development for sustainable landscape governance. *Sustainability Science*, *17*(3), 849–864. https://doi.org/10.1007/s11625-021-00953-8

Harmáčková, Z. V., Yoshida, Y., Sitas, N., Mannetti, L., Martin, A., Kumar, R., Berbés-Blázquez, M., Collins, R., Eisenack, K., Guimaraes, E., Heras, M., Nelson, V., Niamir, A., Ravera, F., Ruiz-Mallén, I., & O'Farrell, P. (2023). The role of values in future scenarios: What types of values underpin (un)sustainable and (un)just futures? *Current Opinion in Environmental Sustainability*, *64*, 101343. https://doi.org/10.1016/j.cosust.2023.101343

Harrison, I. J., Abell, R., Darwall, W., Thieme, M. L., Tickner, D., & Timboe, I. (2018). The freshwater biodiversity crisis. *Science*, *362*(6421), 1369–1369. https://doi.org/10.1126/science.aav9242

Harrison, I. J., Green, P. A., Farrell, T. A., Juffe- Bignoli, D., Sáenz, L., & Vörösmarty, C. J. (2016). Protected areas and freshwater provisioning: A global assessment of freshwater provision, threats and management strategies to support human water security. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *26*(S1), 103–120. https://doi.org/10.1002/aqc.2652

Harrison, P. A., Beauchamp, K., Cooper, J., Dickie, I., Fitch, A., Gooday, R., Hollaway, M., Holman, I. P., Hunt, M., Jones, L., Mondain-Monval, T., Sandars, D., Siriwardena, G., Seaton, F., Smart, S., Thomas, A., West, B., Whittaker, F., Carnell, E., … Dunford, R. W. (2023). An adaptable integrated modelling platform to support rapidly evolving agricultural and environmental policy. *Environmental Modelling & Software*, *169*, 105821. https://doi.org/10.1016/j.envsoft.2023.105821

Harrison, P. A., Dunford, R., Savin, C., Rounsevell, M. D. A., Holman, I. P., Kebede, A. S., & Stuch, B. (2015). Cross-sectoral impacts of climate change and socio-economic change for multiple, European land- and water-based sectors. *Climatic Change*, *128*(3–4), 279–292. https://doi.org/10.1007/s10584-014-1239-4

Harrison, P. A., Dunford, R. W., Holman, I. P., & Rounsevell, M. D. A. (2016). Climate change impact modelling needs to include cross-sectoral interactions. *Nature Climate Change*, *6*(9), 885–890. https://doi.org/10.1038/nclimate3039

Harrison, P. A., Harmáčková, Z., Aloe Karabulut, A., Brotons, L., Cantele, M., Claudet, J., Dunford, R., Guisan, A., Holman, I., Jacobs, S., Kok, K., Lobanova, A., Morán-Ordóñez, A., Pedde, S., Rixen, C., Santos-Martín, F., Schlaepfer, M., Solidoro, C., Sonrel, A., & Hauck, J. (2019). Synthesizing plausible futures for biodiversity and ecosystem services in Europe and Central Asia using scenario archetypes. *Ecology and Society*, *24*(2). https://doi.org/10.5751/ES-10818-240227

Harrison, P. A., Hauck, J., Austrheim, G., Brotons, L., Cantele, M., Claudet, J., Fürst, C., Guisan, A., Harmáčková, Z. V., Lavorel, S., Olsson, G. A., Proença, V., Rixen, C., Santos-Martín, F., Schlaepfer, M., Solidoro, C., Takenov, Z., & Turok, J. (2018). Chapter 5: Current and future interactions between nature and society. In M. D. A. Rounsevell, M. Fischer, A. Torre-Marin Rando, & A. Mader (Eds.), *The regional assessment report on biodiversity and ecosystem services for Europe and Central Asia of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (pp. 571–660). IPBES Secretariat. https://doi.org/10.5281/zenodo.3237429

Hegwood, M., Langendorf, R. E., & Burgess, M. G. (2022). Why win–wins are rare in complex environmental management. *Nature Sustainability*, *5*(8), 674–680. https://doi.org/10.1038/s41893-022-00866-z

Henry, R. C., Alexander, P., Rabin, S., Anthoni, P., Rounsevell, M. D. A., & Arneth, A. (2019). The role of global dietary transitions for safeguarding biodiversity. *Global Environmental Change*, *58*, 101956. https://doi.org/10.1016/j.gloenvcha.2019.101956

Henry, R. C., Arneth, A., Jung, M., Rabin, S. S., Rounsevell, M. D., Warren, F., & Alexander, P. (2022). Global and regional health and food security under strict conservation scenarios. *Nature Sustainability*, *5*(4), 303–310. https://doi.org/10.1038/s41893-021-00844-x

Henry, R. C., Engström, K., Olin, S., Alexander, P., Arneth, A., & Rounsevell, M. D. A. (2018). Food supply and bioenergy production within the global cropland planetary boundary. *PLOS ONE*, *13*(3), e0194695. https://doi.org/10.1371/journal.pone.0194695

Hermoso, V., Filipe, A. F., Segurado, P., & Beja, P. (2018). Freshwater conservation in a fragmented world: Dealing with barriers in a systematic planning framework. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *28*(1), 17–25. https://doi.org/10.1002/aqc.2826

Hermoso, V., Pantus, F., Olley, J., Linke, S., Mugodo, J., & Lea, P. (2012). Systematic planning for river rehabilitation: Integrating multiple ecological and economic objectives in complex decisions. *Freshwater Biology*, *57*(1), 1–9. https://doi.org/10.1111/j.1365-2427.2011.02693.x

Herrera, D., Ellis, A., Fisher, B., Golden, C. D., Johnson, K., Mulligan, M., Pfaff, A., Treuer, T., & Ricketts, T. H. (2017). Upstream watershed condition predicts rural children's health across 35 developing countries. *Nature Communications*, *8*(1), Article 1. https://doi.org/10.1038/s41467-017-00775-2

Hicks, C. C., Cohen, P. J., Graham, N. A. J., Nash, K. L., Allison, E. H., D'Lima, C., Mills, D. J., Roscher, M., Thilsted, S. H., Thorne-Lyman, A. L., & MacNeil, M. A. (2019). Harnessing global fisheries to tackle micronutrient deficiencies. *Nature*, *574*(7776), Article 7776. https://doi.org/10.1038/s41586-019-1592-6

Hinz, R., Sulser, T. B., Huefner, R., Mason-D'Croz, D., Dunston, S., Nautiyal, S., Ringler, C., Schuengel, J., Tikhile, P., Wimmer, F., & Schaldach, R. (2020). Agricultural Development and Land Use Change in India: A Scenario Analysis of Trade-Offs Between UN Sustainable Development Goals (SDGs). *Earth's Future*, *8*(2). https://doi.org/10.1029/2019EF001287

Hoegh-Guldberg, O., Jacob, D., Bindi, M., Brown, S., Camilloni, I., Diedhiou, A., Djalante, R., Ebi, K., Engelbrecht, F., Guiot, J., Hijioka, Y., Mehrotra, S., Payne, A., Seneviratne, S. I., Thomas, A., Warren, R., & Zhou, G. (2018). Impacts of 1.5° C Global Warming on Natural and Human Systems. In *Global warming of 1.5° C.: An IPCC Special Report* (pp. 175–311). https://www.ipcc.ch/site/assets/uploads/sites/2/2019/02/SR15_Chapter3_Low_Res.pdf

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Guillén Bolaños, T., Bindi, M., Brown, S., Camilloni, I. A., Diedhiou, A., Djalante, R., Ebi, K., Engelbrecht, F., Guiot, J., Hijioka, Y., Mehrotra, S., Hope, C. W., Payne, A. J., Pörtner, H.-O., Seneviratne, S. I., Thomas, A., … Zhou, G. (2019). The human imperative of stabilizing global climate change at 1.5°C. *Science*, *365*(6459), eaaw6974. https://doi.org/10.1126/science.aaw6974

Hof, C., Voskamp, A., Biber, M. F., Böhning-Gaese, K., Engelhardt, E. K., Niamir, A., Willis, S. G., & Hickler, T. (2018). Bioenergy cropland expansion may offset positive effects of climate change mitigation for global vertebrate diversity. *Proceedings of the National Academy of Sciences*, *115*(52), 13294–13299. https://doi.org/10.1073/pnas.1807745115

Hosen, N., Nakamura, H., & Hamzah, A. (2020). Adaptation to Climate Change: Does Traditional Ecological Knowledge Hold the Key? *Sustainability*, *12*(2), 676. https://doi.org/10.3390/su12020676

Hosterman, H., Ritter, K., Schuldt, N., Vogt, D., Erickson, D., Griot, O., Johnston, E., Schmidt, K., Ravindran, E., LaBine, R., Chapman, Sr., E., Graveen, W., Peroff, D., Taitano Camacho, J., Dance, S., Krumwiede, B., & Stirratt, H. (2023). Lake Superior Manoomin cultural and ecosystem characterization study. *Ecology and Society*, *28*(3), art17. https://doi.org/10.5751/ES-13763-280317

Hull, V., & Liu, J. (2018). Telecoupling: A new frontier for global sustainability. *Ecology and Society*, *23*(4), art41. https://doi.org/10.5751/ES-10494-230441

Humpenöder, F., Bodirsky, B. L., Weindl, I., Lotze-Campen, H., Linder, T., & Popp, A. (2022). Projected environmental benefits of replacing beef with microbial protein. *Nature*, *605*(7908), 90–96. https://doi.org/10.1038/s41586-022-04629-w

Hyytiäinen, K., Bauer, B., Bly Joyce, K., Ehrnsten, E., Eilola, K., Gustafsson, B. G., Meier, H. E. M., Norkko, A., Saraiva, S., Tomczak, M., & Zandersen, M. (2021). Provision of aquatic ecosystem services as a consequence of societal changes: The case of the Baltic Sea. *Population Ecology*, *63*(1), 61–74. https://doi.org/10.1002/1438-390X.12033

IEA. (2019). *World Energy Outlook 2019* (pp. 1–810). International Energy Agency. https://www.oecd-ilibrary.org/docserver/caf32f3b-en.pdf?expires=1668518394&id=id&accname=ocid54015570&checksum=059E7600973D6C9B80E011A61A9E1C36

Intralawan, A., Wood, D., Frankel, R., Costanza, R., & Kubiszewski, I. (2018). Tradeoff analysis between electricity generation and ecosystem services in the Lower Mekong Basin. *Ecosystem Services*, *30*, 27–35. https://doi.org/10.1016/j.ecoser.2018.01.007

IPBES. (2016). *The methodological assessment report on scenarios and models of biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. IPBES Secretariat. https://doi.org/10.5281/zenodo.3235428

IPBES. (2018a). *The assessment report on land degradation and restoration of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (L. Montanarella, R. Scholes, & A. Brainich, Eds.). Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. https://doi.org/10.5281/zenodo.3237392

IPBES. (2018b). *The IPBES regional assessment report on biodiversity and ecosystem services for Europe and Central Asia*. Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. https://doi.org/10.5281/ZENODO.3237428

IPBES. (2019). *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (E. S. Brondízio, J. Settele, S. Díaz, & H. T. Ngo, Eds.; p. 1082). IPBES Secretariat. https://doi.org/10.5281/zenodo.3831673

IPBES. (2020). *Workshop Report on Biodiversity and Pandemics of the Intergovernmental Platform on Biodiversity and Ecosystem Services*. IPBES. https://doi.org/10.5281/ZENODO.4147317

IPBES. (2022). *Report of the first indigenous and local knowledge dialogue workshop for the IPBES assessments of the nexus of biodiversity, food, water and health and transformative change: Framing the assessments.* IPBES. https://files.ipbes.net/ipbes-web-prod-public-files/2023-02/IPBES_Nex-TrCh_1stILKDialogue_Report_FINAL_forWeb.pdf

IPBES. (2023a). *Summary for Policymakers of the Thematic Assessment Report on Invasive Alien Species and their Control of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (Version 2). Zenodo. https://doi.org/10.5281/ZENODO.8314303

IPBES. (2023b). *The Nature Futures Framework, a flexible tool to support the development of scenarios and models of desirable futures for people, nature and Mother Earth, and its methodological guidance*. https://doi.org/10.5281/ZENODO.8171339

IPCC. (2000). *Emission Scenarios. A Special Report of IPCC Working Group III: Summary for Policymakers*. https://www.ipcc.ch/site/assets/uploads/2018/03/sres-en.pdf

IPCC. (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* (Field, C. B., Barros, D. J., Dokken, K. J., Mach, M. E., Mastrandrea, T. E., Bilir, M., Chatterjee, K. L., Ebi, Y. O., Estrada, R. C., Genova, B., Germa, E. S., Kissel, E. S., Levy, A. N., MacCracken, S., Mastrandrea, P. R., & White, L. L., Eds.). Cambridge University Press. https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-PartA_FINAL.pdf

IPCC. (2019). *Climate Change and Land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)].* https://www.ipcc.ch/site/assets/uploads/sites/4/2021/07/210714-

IPCCJ7230-SRCCL-Complete-BOOK-HRES.pdf

IPCC. (2021). *Climate Change 2021: The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]* (1st ed.). Cambridge University Press. https://doi.org/10.1017/9781009157896

IPCC. (2022a). *Climate Change 2022: Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Pörtner, H.-O., Roberts, D. C., Tignor, M., Poloczanska, E. S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A., & Rama, B., Eds.). Cambridge University Press. https://doi.org/10.1017/9781009325844

IPCC. (2022b). *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]*. Cambridge University Press, Cambridge, UK and New York, NY, USA. https://doi.org/10.1017/9781009157926

IPCC. (2023). *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Core Writing Team, Lee, H., & Romero, J., Eds.). IPCC. https://doi.org/10.59327/IPCC/AR6-9789291691647

Iungman, T., Cirach, M., Marando, F., Pereira Barboza, E., Khomenko, S., Masselot, P., Quijal-Zamorano, M., Mueller, N., Gasparrini, A., Urquiza, J., Heris, M., Thondoo, M., & Nieuwenhuijsen, M. (2023). Cooling cities through urban green infrastructure: A health impact assessment of European cities. *The Lancet*, *401*(10376), 577–589. https://doi.org/10.1016/S0140-6736(22)02585-5

Ivanovich, C. C., Sun, T., Gordon, D. R., & Ocko, I. B. (2023). Future warming from global food consumption. *Nature Climate Change*. https://doi.org/10.1038/s41558-023-01605-8

Jaakkola, J. J. K., Juntunen, S., & Näkkäläjärvi, K. (2018). The Holistic Effects of Climate Change on the Culture, Well-Being, and Health of the Saami, the Only Indigenous People in the European Union. *Current Environmental Health Reports*, *5*(4), 401–417. https://doi.org/10.1007/s40572-018-0211-2

Jägermeyr, J., Müller, C., Ruane, A. C., Elliott, J., Balkovic, J., Castillo, O., Faye, B., Foster, I., Folberth, C., Franke, J. A., Fuchs, K., Guarin, J. R., Heinke, J., Hoogenboom, G., Iizumi, T., Jain, A. K., Kelly, D., Khabarov, N., Lange, S., … Rosenzweig, C. (2021). Climate impacts on global agriculture emerge earlier in new generation of climate and crop models. *Nature Food*, *2*(11), 873–885. https://doi.org/10.1038/s43016-021-00400-y

Jalilov, S.-M., Amer, S. A., & Ward, F. A. (2018). Managing the water-energy-food nexus: Opportunities in Central Asia. *Journal of Hydrology*, *557*, 407–425. https://doi.org/10.1016/j.jhydrol.2017.12.040

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Narayan, R., & Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science*, *347*(6223), 768–771. https://doi.org/10.1126/science.1260352

Jardine, A., Lindsay, M. D. A., Johansen, C. A., Cook, A., & Weinstein, P. (2008). Impact of Dryland Salinity on Population Dynamics of Vector Mosquitoes (Diptera: Culicidae) of Ross River Virus in Inland Areas of Southwestern Western Australia. *Journal of Medical Entomology*, *45*(6), 1011–1022. https://doi.org/10.1093/jmedent/45.6.1011

Jetz, W., McGeoch, M. A., Guralnick, R., Ferrier, S., Beck, J., Costello, M. J., Fernandez, M., Geller, G. N., Keil, P., Merow, C., Meyer, C., Muller-Karger, F. E., Pereira, H. M., Regan, E. C., Schmeller, D. S., & Turak, E. (2019). Essential biodiversity variables for mapping and monitoring species populations. *Nature Ecology & Evolution*, *3*(4), 539–551. https://doi.org/10.1038/s41559-019-0826-1

Jha, C. K., Singh, V., Stevanović, M., Dietrich, J. P., Mosnier, A., Weindl, I., Popp, A., Traub, G. S., Ghosh, R. K., & Lotze-Campen, H. (2022a). The role of food and land use systems in achieving India's sustainability targets. *Environmental Research Letters*, *17*(7), 074022. https://doi.org/10.1088/1748-9326/ac788a

Jha, C. K., Singh, V., Stevanović, M., Dietrich, J. P., Mosnier, A., Weindl, I., Popp, A., Traub, G. S., Ghosh, R. K., & Lotze-Campen, H. (2022b). The role of food and land use systems in achieving India's sustainability targets. *Environmental Research Letters*, *17*(7), Article 7. https://doi.org/10.1088/1748-9326/ac788a

Jin, X., Bai, Z., Zhao, H., Wang, X., Chang, J., Hua, F., & Ma, L. (2020). *"Pathways to Sustainable Land-Use and Food Systems in China by 2050" In: FABLE 2020, Pathways to Sustainable Land-Use and Food Systems.* (pp. 195–229). International Institute for Applied Systems Analysis (IIASA) and Sustainable Development Solutions Network (SDSN). http://pure.iiasa.ac.at/id/eprint/16896/

Johnson, D. E., Parsons, M., & Fisher, K. (2022). Indigenous climate change adaptation: New directions for emerging scholarship. *Environment and Planning E: Nature and Space*, *5*(3), 1541–1578. https://doi.org/10.1177/25148486211022450

Johnson, N., Burek, P., Byers, E., Falchetta, G., Flörke, M., Fujimori, S., Havlik, P., Hejazi, M., Hunt, J., Krey, V., Langan, S., Nakicenovic, N., Palazzo, A., Popp, A., Riahi, K., van Dijk, M., van Vliet, M., van Vuuren, D., Wada, Y., … Parkinson, S. (2019). Integrated Solutions for the Water-Energy-Land Nexus: Are Global Models Rising to the Challenge? *Water*, *11*(11), 2223. https://doi.org/10.3390/w11112223

Jones, M. C., & Cheung, W. W. L. (2015). Multi-model ensemble projections of climate change effects on global marine biodiversity. *ICES Journal of Marine Science*, *72*(3), 741–752. https://doi.org/10.1093/icesjms/fsu172

Jones, S. K., Monjeau, A., Perez-Guzman, K., & Harrison, P. A. (2023). Integrated modeling to achieve global goals: Lessons from the Food, Agriculture, Biodiversity, Land-use, and Energy (FABLE) initiative. *Sustainability Science*, *18*(1), 323–333. https://doi.org/10.1007/s11625-023-01290-8

Judson, S. D., & Rabinowitz, P. M. (2021). Zoonoses and global epidemics. *Current Opinion in Infectious Diseases*, *34*(5), 385–392. https://doi.org/10.1097/QCO.0000000000000749

Jung, M., Alagador, D. A., Chapman, M., Hermoso, V., Kujala, H., O'Connor, L., Schinegger, R., Verburg, P. H., & Visconti, P. (2023). An assessment of the state of conservation planning in Europe. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *379*(1902). https://doi.org/10.1098/rstb.2023.0015

Jung, M., Arnell, A., de Lamo, X., García-Rangel, S., Lewis, M., Mark, J., Merow, C., Miles, L., Ondo, I., Pironon, S., Ravilious, C., Rivers, M., Schepaschenko, D., Tallowin, O., van Soesbergen, A., Govaerts, R., Boyle, B. L., Enquist, B. J., Feng, X., … Visconti, P. (2021). Areas of global importance for conserving terrestrial biodiversity, carbon and water. *Nature Ecology & Evolution*, *5*(11), 1499–1509. https://doi.org/10.1038/s41559-021-01528-7

Jung, M., Lesiv, M., Warren-Thomas, E., Shchepashchenko, D., See, L., & Fritz, S. (2023). The importance of capturing management in forest restoration targets. *Nature Sustainability*, *6*(11), 1321–1325. https://doi.org/10.1038/s41893-023-01192-8

Karki, K. (2022). *Risk and uncertainty attitude and climate change perception of forestry professionals in Nepal in line with IPBES NFF narratives* [Albert-Ludwigs-Universitat Freiburg]. https://erepo.uef.fi/bitstream/handle/123456789/28784/urn_nbn_fi_uef-20221366.pdf;jsessionid=0A9C3223E6C2BDB39059D488B6397484?sequence=1

Kelman, I., Ayeb-Karlsson, S., Rose-Clarke, K., Prost, A., Ronneberg, E., Wheeler, N., & Watts, N. (2021). A review of mental health and wellbeing under climate change in small island developing states (SIDS). *Environmental Research Letters*, *16*(3), 033007. https://doi.org/10.1088/1748-9326/abe57d

Khan, S. U., Ogden, N. H., Fazil, A. A., Gachon, P. H., Dueymes, G. U., Greer, A. L., & Ng, V. (2020). Current and Projected Distributions of *Aedes aegypti* and *Ae. Albopictus* in Canada and the U.S. *Environmental Health Perspectives*, *128*(5), 057007. https://doi.org/10.1289/EHP5899

Kim, B. F., Santo, R. E., Scatterday, A. P., Fry, J. P., Synk, C. M., Cebron, S. R., Mekonnen, M. M., Hoekstra, A. Y., de Pee, S., Bloem, M. W., Neff, R. A., & Nachman, K. E. (2020). Country-specific dietary shifts to mitigate climate and water crises. *Global Environmental Change*, *62*, 101926. https://doi.org/10.1016/j.gloenvcha.2019.05.010

Kim, H., Peterson, G. D., Cheung, W. W. L., Ferrier, S., Alkemade, R., Arneth, A., Kuiper, J. J., Okayasu, S., Pereira, L., Acosta, L. A., Chaplin-Kramer, R., den Belder, E., Eddy, T. D., Johnson, J. A., Karlsson-Vinkhuyzen, S., Kok, M. T. J., Leadley, P., Leclère, D., Lundquist, C. J., … Pereira, H. M. (2023). Towards a better future for biodiversity and people: Modelling Nature Futures. *Global Environmental Change*, *82*, 102681. https://doi.org/10.1016/j.gloenvcha.2023.102681

Kimani-Murage, E., Gaupp, F., Lal, R., Hansson, H., Tang, T., Chaudhary, A., Nhamo, L., Mpandeli, S., Mabhaudhi, T., Headey, D. D., Hirvonen, K., & Afsana, K. (2021). An optimal diet for planet and people. *One Earth*, *4*(9), 1189–1192. https://doi.org/10.1016/j.oneear.2021.08.017

Kleisner, K. M., Fogarty, M. J., McGee, S., Hare, J. A., Moret, S., Perretti, C. T., & Saba, V. S. (2017). Marine species distribution shifts on the U.S. Northeast Continental Shelf under continued ocean warming. *Progress in Oceanography*, *153*, 24–36. https://doi.org/10.1016/j.pocean.2017.04.001

Klinger, D. H., Levin, S. A., & Watson, J. R. (2017). The growth of finfish in global open-ocean aquaculture under climate change. *Proceedings of the Royal Society B: Biological Sciences*, *284*(1864), 20170834. https://doi.org/10.1098/rspb.2017.0834

Köhler, C. F., Holding, M. L., Sprong, H., Jansen, P. A., & Esser, H. J. (2023). Biodiversity in the Lyme-light: Ecological restoration and tick-borne diseases in Europe. *Trends in Parasitology*, *39*(5), 373–385. https://doi.org/10.1016/j.pt.2023.02.005

Kok, M. T. J., Alkemade, R., Bakkenes, M., van Eerdt, M., Janse, J., Mandryk, M., Kram, T., Lazarova, T., Meijer, J., van Oorschot, M., Westhoek, H., van der Zagt, R., van der Berg, M., van der Esch, S., Prins, A.-G., & van Vuuren, D. P. (2018). Pathways for agriculture and forestry to contribute to terrestrial biodiversity conservation: A global scenario-study. *Biological Conservation*, *221*, 137–150. https://doi.org/10.1016/j.biocon.2018.03.003

Kok, M. T. J., Meijer, J. R., Van Zeist, W.-J., Hilbers, J. P., Immovilli, M., Janse, J. H., Stehfest, E., Bakkenes, M., Tabeau, A., Schipper, A. M., & Alkemade, R. (2023). Assessing ambitious nature conservation strategies in a below 2-degree and food-secure world. *Biological Conservation*, *284*, 110068. https://doi.org/10.1016/j.biocon.2023.110068

Kookana, R. S., Drechsel, P., Jamwal, P., & Vanderzalm, J. (2020). Urbanisation and emerging economies: Issues and potential solutions for water and food security. *Science of The Total Environment*, *732*, 139057. https://doi.org/10.1016/j.scitotenv.2020.139057

Koven, C., Arora, V., Cadule, P., Fisher, R., Jones, C., Lawrence, D., Lewis, J., Lindsey, K., Mathesius, S., Meinshausen, M., Mills, M., Nicholls, Z., Sanderson, B., Swart, N., Wieder, W., & Zickfeld, K. (2022). 23rd Century surprises: Long-term dynamics of the climate and carbon cycle under both high and net negative emissions scenarios. *Earth System Dynamics*. https://doi.org/10.5194/esd-2021-23

Kozicka, M., Havlík, P., Valin, H., Wollenberg, E., Deppermann, A., Leclère, D., Lauri, P., Moses, R., Boere, E., Frank, S., Davis, C., Park, E., & Gurwick, N. (2023). Feeding climate and biodiversity goals with novel plant-based meat and milk alternatives. *Nature Communications*, *14*(1), 5316. https://doi.org/10.1038/s41467-023-40899-2

Kraemer, M. U. G., Reiner, R. C., Brady, O. J., Messina, J. P., Gilbert, M., Pigott, D. M., Yi, D., Johnson, K., Earl, L., Marczak, L. B., Shirude, S., Davis Weaver, N., Bisanzio, D., Perkins, T. A., Lai, S., Lu, X., Jones, P., Coelho, G. E., Carvalho, R. G., … Golding, N. (2019). Past and future spread of the arbovirus vectors Aedes aegypti and Aedes albopictus. *Nature Microbiology*, *4*(5), Article 5. https://doi.org/10.1038/s41564-019-0376-y

Krause, A., Haverd, V., Poulter, B., Anthoni, P., Quesada, B., Rammig, A., & Arneth, A. (2019). Multimodel Analysis of Future Land Use and Climate Change Impacts on Ecosystem Functioning. *Earth's Future*, *7*(7), 833–851. https://doi.org/10.1029/2018EF001123

Krchnak, K., Smith, D., & Deutz, A. (2011). Putting nature in the nexus: Investing in natural infrastructure to advance water-energy-food security. *Bonn 2011 Conference: The Water, Energy, and Food Security Nexus–Solutions for the Green Economy. Background Papers for the Stakeholder Engagement Process*. https://iucn.org/sites/default/files/import/downloads/nexus_report.pdf

Kuby, M. J., Fagan, W. F., ReVelle, C. S., & Graf, W. L. (2005). A multiobjective optimization model for dam removal: An example trading off salmon passage with hydropower and water storage in the Willamette basin. *Advances in Water Resources*, *28*(8), 845–855. https://doi.org/10.1016/j.advwatres.2004.12.015

Kuiper, J. J., van Wijk, D., Mooij, W. M., Remme, R. P., Peterson, G. D., Karlsson-Vinkhuyzen, S., Mooij, C. J., Leltz, G. M., & Pereira, L. M. (2022). Exploring desirable nature futures for Nationaal Park Hollandse Duinen. *Ecosystems and People*, *18*(1), 329–347. https://doi.org/10.1080/26395916.2022.2065360

Kumar, P. (2019). Numerical quantification of current status quo and future prediction of water quality in eight Asian megacities: Challenges and opportunities for sustainable water management. *Environmental Monitoring and Assessment*, *191*(6), 319. https://doi.org/10.1007/s10661-019-7497-x

Kuntiyawichai, K., Schultz, B., Uhlenbrook, S., Suryadi, F. X., & Van Griensven, A. (2011). Comparison of flood management options for the Yang River Basin, Thailand. *Irrigation and Drainage*, *60*(4), 526–543. https://doi.org/10.1002/ird.596

Kupkanchanakul, W., Kwonpongsagoon, S., Bader, H.-P., & Scheidegger, R. (2015). Integrating Spatial Land Use Analysis and Mathematical Material Flow Analysis for Nutrient Management: A Case Study of the Bang Pakong River Basin in Thailand. *Environmental Management*, *55*(5), 1022–1035. https://doi.org/10.1007/s00267-014-0441-5

Lam, D. P. M., Hinz, E., Lang, D. J., Tengö, M., Wehrden, H. von, & Martín-López, B. (2020). Indigenous and local knowledge in sustainability transformations research: A literature review. *Ecology and Society*, *25*(1), art3. https://doi.org/10.5751/ES-11305-250103

Lamb, W. F., Wiedmann, T., Pongratz, J., Andrew, R., Crippa, M., Olivier, J. G. J., Wiedenhofer, D., Mattioli, G., Khourdajie, A. A., House, J., Pachauri, S., Figueroa, M., Saheb, Y., Slade, R., Hubacek, K., Sun, L., Ribeiro, S. K., Khennas, S., Can, S. de la R. du, … Minx, J. (2021). A review of trends and drivers of greenhouse gas emissions by sector from 1990 to 2018. *Environmental Research Letters*, *16*(7), 073005. https://doi.org/10.1088/1748-9326/abee4e

Lanzas, M., Hermoso, V., de-Miguel, S., Bota, G., & Brotons, L. (2019). Designing a network of green infrastructure to enhance the conservation value of protected areas and maintain ecosystem services. *Science of The Total Environment*, *651*, 541–550. https://doi.org/10.1016/j.scitotenv.2018.09.164

Lapeyrolerie, M., Chapman, M. S., Norman, K. E. A., & Boettiger, C. (2022). Deep reinforcement learning for conservation decisions. *Methods in Ecology and Evolution*, *13*(11), 2649–2662. https://doi.org/10.1111/2041-210X.13954

Latinne, A., Hu, B., Olival, K. J., Zhu, G., Zhang, L., Li, H., Chmura, A. A., Field, H. E., Zambrana-Torrelio, C., Epstein, J. H., Li, B., Zhang, W., Wang, L.-F., Shi, Z.-L., & Daszak, P. (2020). Origin and cross-species transmission of bat coronaviruses in China. *Nature Communications*, *11*(1), 4235. https://doi.org/10.1038/s41467-020-17687-3

Law, E. A., Macchi, L., Baumann, M., Decarre, J., Gavier-Pizarro, G., Levers, C., Mastrangelo, M. E., Murray, F., Müller, D., Piquer-Rodríguez, M., Torres, R., Wilson, K. A., & Kuemmerle, T. (2021). Fading opportunities for mitigating agriculture-environment trade-offs in a south American deforestation hotspot. *Biological Conservation*, *262*, 109310. https://doi.org/10.1016/j.biocon.2021.109310

Leadley, P., Gonzalez, A., Obura, D., Krug, C. B., Londoño-Murcia, M. C., Millette, K. L., Radulovici, A., Rankovic, A., Shannon, L. J., Archer, E., Armah, F. A., Bax, N., Chaudhari, K., Costello, M. J., Dávalos, L. M., Roque, F. de O., DeClerck, F., Dee, L. E., Essl, F., … Xu, J. (2022). Achieving global biodiversity goals by 2050 requires urgent and integrated actions. *One Earth*, *5*(6), 597–603. https://doi.org/10.1016/j.oneear.2022.05.009

Leadley, P. W., Krug, C. B., Alkemade, R., Pereira, H. M., Sumaila, U. R., Walpole, M., Marques, A., Newbold, T., Teh, L. S. L., van Kolck, J., Bellard, C., Januchowski-Hartley, S. R., & Mumby, P. J. (2014). *Progress towards the Aichi biodiversity targets: An assessment of biodiversity trends, policy scenarios and key actions : Global biodiversity outlook 4 (GBO-4) technical report*. Secretariat of the Convention on Biological Diversity. https://www.cbd.int/doc/publications/cbd-ts-78-en.pdf

Leal, C. G., Lennox, G. D., Ferraz, S. F. B., Ferreira, J., Gardner, T. A., Thomson, J. R., Berenguer, E., Lees, A. C., Hughes, R. M., Mac Nally, R., Aragão, L. E. O. C., De Brito, J. G., Castello, L., Garrett, R. D., Hamada, N., Juen, L., Leitão, R. P., Louzada, J., Morello, T. F., … Barlow, J. (2020). Integrated terrestrial-freshwater planning doubles conservation of tropical aquatic species. *Science*, *370*(6512), 117–121. https://doi.org/10.1126/science.aba7580

Leclère, D., Obersteiner, M., Alkemade, R., Almond, R., Barrett, M., Bunting, G., Burgess, N., Butchart, S., Chaudhary, A., Cornell, S., De Palma, A., DeClerck, F., Di Fulvio, F., Di Marco, M., Doelman, J., Durauer, M., Ferrier, S., Freeman, R., Fritz, S., … Young, L. (2018). *Towards pathways bending the curve terrestrial biodiversity trends within the 21st century* [PDF]. International Institute Of Applied System Analysis. https://doi.org/10.22022/ESM/04-2018.15241

Leclère, D., Obersteiner, M., Barrett, M., Butchart, S. H. M., Chaudhary, A., De Palma, A., DeClerck, F. A. J., Di Marco, M., Doelman, J. C., Dürauer, M., Freeman, R., Harfoot, M., Hasegawa, T., Hellweg, S., Hilbers, J. P., Hill, S. L. L., Humpenöder, F., Jennings, N., Krisztin, T., … Young, L. (2020). Bending the curve of terrestrial biodiversity needs an integrated strategy. *Nature*, *585*(7826), 551–556. https://doi.org/10.1038/s41586-020-2705-y

Lee, H., Brown, C., Seo, B., Holman, I., Audsley, E., Cojocaru, G., & Rounsevell, M. D. A. (2019). Implementing land-based mitigation to achieve the Paris Agreement in Europe requires food system transformation. *Environmental Research Letters*, *14*(10), 104009. https://doi.org/10.1088/1748-9326/ab3744

Lehtonen, H., & Rämö, J. (2022). Development towards low carbon and sustainable agriculture in Finland is possible with moderate changes in land use and diets. *Sustainability Science*. https://doi.org/10.1007/s11625-022-01244-6

Lemaire, G. G., Jessen Rasmussen, J., Höss, S., Figari Kramer, S., Schittich, A.-R., Zhou, Y., Köppl, C. J., Traunspurger, W., Bjerg, P. L., & McKnight, U. S. (2022). Land use contribution to spatiotemporal stream water and ecological quality: Implications for water resources management in peri-urban catchments. *Ecological Indicators*, *143*. Scopus. https://doi.org/10.1016/j.ecolind.2022.109360

Lenzen, M., Moran, D., Kanemoto, K., Foran, B., Lobefaro, L., & Geschke, a. (2012). International trade drives biodiversity threats in developing nations. *Nature*, *486*, 109–112. https://doi.org/10.1038/nature11145

Lester, S. E., Dubel, A. K., Hernán, G., McHenry, J., & Rassweiler, A. (2020). Spatial Planning Principles for Marine Ecosystem Restoration. *Frontiers in Marine Science*, *7*. https://doi.org/10.3389/fmars.2020.00328

Levin, L. A., Alfaro-Lucas, J. M., Colaço, A., Cordes, E. E., Craik, N., Danovaro, R., Hoving, H.-J., Ingels, J., Mestre, N. C., Seabrook, S., Thurber, A. R., Vivian, C., & Yasuhara, M. (2023). Deep-sea impacts of climate interventions. *Science*, *379*(6636), 978–981. https://doi.org/10.1126/science.ade7521

Li, H., Mendelsohn, E., Zong, C., Zhang, W., Hagan, E., Wang, N., Li, S., Yan, H., Huang, H., Zhu, G., Ross, N., Chmura, A., Terry, P., Fielder, M., Miller, M., Shi, Z., & Daszak, P. (2019). Human-animal interactions and bat coronavirus spillover potential among rural residents in Southern China. *Biosafety and Health*, *1*(2), 84–90. https://doi.org/10.1016/j.bsheal.2019.10.004

Li, H.-Y., Zhu, G.-J., Zhang, Y.-Z., Zhang, L.-B., Hagan, E. A., Martinez, S., Chmura, A. A., Francisco, L., Tai, H., Miller, M., & Daszak, P. (2020). A qualitative study of zoonotic risk factors among rural communities in southern China. *International Health*, *12*(2), 77–85. https://doi.org/10.1093/inthealth/ihaa001

Li, J., Chen, X., Kurban, A., Van de Voorde, T., De Maeyer, P., & Zhang, C. (2021). Coupled SSPs-RCPs scenarios to project the future dynamic variations of water-soil-carbon-biodiversity services in Central Asia. *Ecological Indicators*, *129*, 107936. https://doi.org/10.1016/j.ecolind.2021.107936

Liu, J., Hull, V., Batistella, M., DeFries, R., Dietz, T., Fu, F., Hertel, T., Izaurralde, R. C., Lambin, E., Li, S., Martinelli, L., McConnell, W., Moran, E., Naylor, R., Ouyang, Z., Polenske, K., Reenberg, A., de Miranda Rocha, G., Simmons, C., … Zhu, C. (2013). Framing Sustainability in a Telecoupled World. *Ecology and Society*, *18*(2). https://doi.org/10.5751/ES-05873-180226

Liu, J., Hull, V., Godfray, H. C. J., Tilman, D., Gleick, P., Hoff, H., Pahl-Wostl, C., Xu, Z., Chung, M. G., Sun, J., & Li, S. (2018). Nexus approaches to global sustainable development. *Nature Sustainability*, *1*(9), Article 9. https://doi.org/10.1038/s41893-018-0135-8

Liu, K., Li, X., Wang, S., & Zhang, X. (2023). Unrevealing past and future vegetation restoration on the Loess Plateau and its impact on terrestrial water storage. *JOURNAL OF HYDROLOGY*, *617*, 129021. https://doi.org/10.1016/j.jhydrol.2022.129021

Lloret, J., Palomera, I., Salat, J., & Sole, I. (2004). Impact of freshwater input and wind on landings of anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*) in shelf waters surrounding the Ebre (Ebro) River delta (north-western Mediterranean). *Fisheries Oceanography*, *13*(2), 102–110. https://doi.org/10.1046/j.1365-2419.2003.00279.x

Lopez Barrera, E., & Hertel, T. (2021). Global food waste across the income spectrum: Implications for food prices, production and resource use. *Food Policy*, *98*, 101874. https://doi.org/10.1016/j.foodpol.2020.101874

Lotze, H. K., Lenihan, H. S., Bourque, B. J., Bradbury, R. H., Cooke, R. G., Kay, M. C., Kidwell, S. M., Kirby, M. X., Peterson, C. H., & Jackson, J. B. C. (2006). Depletion, Degradation, and Recovery Potential of Estuaries and Coastal Seas. *Science*, *312*(5781), 1806–1809. https://doi.org/10.1126/science.1128035

Lotze, H. K., Tittensor, D. P., Bryndum-Buchholz, A., Eddy, T. D., Cheung, W. W. L., Galbraith, E. D., Barange, M., Barrier, N., Bianchi, D., Blanchard, J. L., Bopp, L., Büchner, M., Bulman, C. M., Carozza, D. A., Christensen, V., Coll, M., Dunne, J. P., Fulton, E. A., Jennings, S., … Worm, B. (2019). Global ensemble projections reveal trophic amplification of ocean biomass declines with climate change. *Proceedings of the National Academy of Sciences*, *116*(26), 12907–12912. https://doi.org/10.1073/pnas.1900194116

Lovelock, C. E., Adame, M. F., Bradley, J., Dittmann, S., Hagger, V., Hickey, S. M., Hutley, L. B., Jones, A., Kelleway, J. J., Lavery, P. S., Macreadie, P. I., Maher, D. T., McGinley, S., McGlashan, A., Perry, S., Mosley, L., Rogers, K., & Sippo, J. Z. (2023). An Australian blue carbon method to estimate climate change mitigation benefits of coastal wetland restoration. *Restoration Ecology*, *31*(7), e13739. https://doi.org/10.1111/rec.13739

Luderer, G., Madeddu, S., Merfort, L., Ueckerdt, F., Pehl, M., Pietzcker, R., Rottoli, M., Schreyer, F., Bauer, N., Baumstark, L., Bertram, C., Dirnaichner, A., Humpenöder, F., Levesque, A., Popp, A., Rodrigues, R., Strefler, J., & Kriegler, E. (2022). Impact of declining renewable energy costs on electrification in low-emission scenarios. *Nature Energy*, *7*(1), 32–42. https://doi.org/10.1038/s41560-021-00937-z

Lyon, C., Saupe, E. E., Smith, C. J., Hill, D. J., Beckerman, A. P., Stringer, L. C., Marchant, R., McKay, J., Burke, A., O'Higgins, P., Dunhill, A. M., Allen, B. J., Riel-Salvatore, J., & Aze, T. (2022). Climate change research and action must look beyond 2100. *Global Change Biology*, *28*(2), 349–361. https://doi.org/10.1111/gcb.15871

Lyons, I., Hill, R., Deshong, S., Mooney, G., & Turpin, G. (2020). Protecting what is left after colonisation: Embedding climate adaptation planning in traditional owner narratives. *Geographical Research*, *58*(1), 34–48. https://doi.org/10.1111/1745-5871.12385

Ma, Y., Li, Y. P., Huang, G. H., & Zhang, Y. F. (2023). Sustainable management of water-agriculture-ecology nexus system under multiple uncertainties. *Journal of Environmental Management*, *341*, 118096. https://doi.org/10.1016/j.jenvman.2023.118096

Mace, G. M., Barrett, M., Burgess, N. D., Cornell, S. E., Freeman, R., Grooten, M., & Purvis, A. (2018). Aiming higher to bend the curve of biodiversity loss. *Nature Sustainability*, *1*(9), Article 9. https://doi.org/10.1038/s41893-018-0130-0

Machovina, B., Feeley, K. J., & Ripple, W. J. (2015). Biodiversity conservation: The key is reducing meat consumption. *Science of The Total Environment*, *536*, 419–431. https://doi.org/10.1016/j.scitotenv.2015.07.022

Macreadie, P. I., Costa, M. D. P., Atwood, T. B., Friess, D. A., Kelleway, J. J., Kennedy, H., Lovelock, C. E., Serrano, O., & Duarte, C. M. (2021). Blue carbon as a natural climate solution. *Nature Reviews Earth & Environment*, *2*(12), 826–839. https://doi.org/10.1038/s43017-021-00224-1

Magouras, I., Brookes, V. J., Jori, F., Martin, A., Pfeiffer, D. U., & Dürr, S. (2020). Emerging zoonotic diseases: Should we rethink the animal–human interface? *Frontiers in Veterinary Science*, *7*, 582743. https://doi.org/10.3389/fvets.2020.582743

Maire, J., Sattar, A., Henry, R., Warren, F., Merkle, M., Rounsevell, M. D. A., & Alexander, P. (2022). How different COVID-19 recovery paths affect human health, environmental sustainability, and food affordability: A modelling study. *The Lancet Planetary Health*, *6*(7), e565–e576. https://doi.org/10.1016/S2542-5196(22)00144-9

Makondo, C. C., & Thomas, D. S. G. (2018). Climate change adaptation: Linking indigenous knowledge with western science for effective adaptation. *Environmental Science & Policy*, *88*, 83–91. https://doi.org/10.1016/j.envsci.2018.06.014

Manici, L. M., Bregaglio, S., Fumagalli, D., & Donatelli, M. (2014). Modelling soil borne fungal pathogens of arable crops under climate change. *International Journal of Biometeorology*, *58*(10), 2071–2083. https://doi.org/10.1007/s00484-014-0808-6

Maraud, S., & Roturier, S. (2023). Producing futures for the Arctic: What agency for Indigenous communities in foresight arenas? *Futures*, *153*, 103240. https://doi.org/10.1016/j.futures.2023.103240

Mariani, G., Cheung, W. W. L., Lyet, A., Sala, E., Mayorga, J., Velez, L., Gaines, S. D., Dejean, T., Troussellier, M., & Mouillot, D. (2020). Let more big fish sink: Fisheries prevent blue carbon sequestration—half in unprofitable areas. *Science Advances*, *6*(44), eabb4848. https://doi.org/10.1126/sciadv.abb4848

Markovic, D., Carrizo, S. F., Kärcher, O., Walz, A., & David, J. N. W. (2017). Vulnerability of European freshwater catchments to climate change. *Global Change Biology*, *23*(9), 3567–3580. https://doi.org/10.1111/gcb.13657

Marushka, L., Kenny, T.-A., Batal, M., Cheung, W. W. L., Fediuk, K., Golden, C. D., Salomon, A. K., Sadik, T., Weatherdon, L. V., & Chan, H. M. (2019). Potential impacts of climate-related decline of seafood harvest on nutritional status of coastal First Nations in British Columbia, Canada. *PLOS ONE*, *14*(2), e0211473. https://doi.org/10.1371/journal.pone.0211473

Maúre, E. de R., Terauchi, G., Ishizaka, J., Clinton, N., & DeWitt, M. (2021). Globally consistent assessment of coastal eutrophication. *Nature Communications*, *12*(1), Article 1. https://doi.org/10.1038/s41467-021-26391-9

Mburu, G. (2016). *Reviving Indigenous and local knowledge for restoration of degraded ecosystems in Kenya: A contribution to the Piloting of the Multiple Evidence Base Approach*. SwedBio, African Biodiversity Network. https://www.learningfornature.org/wp-content/uploads/2022/12/MEB-Pilot-Report-Kenya_2016.pdf

McElwee, P., Fernández-Llamazares, Á., Aumeeruddy-Thomas, Y., Babai, D., Bates, P., Galvin, K., Guèze, M., Liu, J., Molnár, Z., Ngo, H. T., Reyes-García, V., Roy Chowdhury, R., Samakov, A., Shrestha, U. B., Díaz, S., & Brondízio, E. S. (2020). Working with Indigenous and local knowledge (ILK) in large-scale ecological assessments: Reviewing the experience of the IPBES Global Assessment. *Journal of Applied Ecology*, *57*(9), 1666–1676. https://doi.org/10.1111/1365-2664.13705

McHenry, J., Welch, H., Lester, S. E., & Saba, V. (2019). Projecting marine species range shifts from only temperature can mask climate vulnerability. *Global Change Biology*, *25*(12), 4208–4221. https://doi.org/10.1111/gcb.14828

McIntyre, P. B., Reidy Liermann, C. A., & Revenga, C. (2016). Linking freshwater fishery management to global food security and biodiversity conservation. *Proceedings of the National Academy of Sciences*, *113*(45), 12880–12885. https://doi.org/10.1073/pnas.1521540113

Mcleod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., Lovelock, C. E., Schlesinger, W. H., & Silliman, B. R. (2011). A blueprint for blue carbon: Toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. *Frontiers in Ecology and the Environment*, *9*(10), 552–560. https://doi.org/10.1890/110004

Menéndez, P., Losada, I. J., Torres-Ortega, S., Narayan, S., & Beck, M. W. (2020). The Global Flood Protection Benefits of Mangroves. *Scientific Reports*, *10*(1), Article 1. https://doi.org/10.1038/s41598-020-61136-6

Meredith, M., Sommerkorn, M., Cassotta, C., Derksen, C., Ekaykin, A., Hollowed, G., Kofinas, A., Mackintosh, J., Melbourne-Thomas, J., Muelbert, M. M. C., Ottersen, G., Pritchard, H., & Schuur, E. A. G. (2019). Polar Regions. In Pörtner, H.-O., Roberts, D. C., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E. S., Mintenbeck, K., Alegría, A., Nicolai, M., Okem, A., Petzold, J., Rama, B., & Weyer, N. M. (Eds.), *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. Cambridge University Press. https://doi.org/10.1017/9781009157964.005

Merfort, L., Bauer, N., Humpenöder, F., Klein, D., Strefler, J., Popp, A., Luderer, G., & Kriegler, E. (2023). Bioenergy-induced land-use-change emissions with sectorally fragmented policies. *Nature Climate Change*, *13*(7), 685–692. https://doi.org/10.1038/s41558-023-01697-2

Messina, J. P., Brady, O. J., Golding, N., Kraemer, M. U. G., Wint, G. R. W., Ray, S. E., Pigott, D. M., Shearer, F. M., Johnson, K., Earl, L., Marczak, L. B., Shirude, S., Davis Weaver, N., Gilbert, M., Velayudhan, R., Jones, P., Jaenisch, T., Scott, T. W., Reiner, R. C., & Hay, S. I. (2019). The current and future global distribution and population at risk of dengue. *Nature Microbiology*, *4*(9), 1508–1515. https://doi.org/10.1038/s41564-019-0476-8

Moallemi, E. A., Eker, S., Gao, L., Hadjikakou, M., Liu, Q., Kwakkel, J., Reed, P. M., Obersteiner, M., Guo, Z., & Bryan, B. A. (2022). Early systems change necessary for catalyzing long-term sustainability in a post-2030 agenda. *One Earth*, *5*(7), 792–811. https://doi.org/10.1016/j.oneear.2022.06.003

Molla, K. G., & Woldeyes, F. B. (2020). *Pathways to Sustainable Land-Use and Food Systems in Ethiopia by 2050* (pp. 262–291). http://pure.iiasa.ac.at/id/eprint/16896/

Momblanch, A., Kelkar, N., Braulik, G., Krishnaswamy, J., & Holman, I. P. (2022). Exploring trade-offs between SDGs for Indus River Dolphin conservation and human water security in the regulated Beas River, India. *Sustainability Science*, *17*(4), 1619–1637. https://doi.org/10.1007/s11625-021-01026-6

Moors, E., Singh, T., Siderius, C., Balakrishnan, S., & Mishra, A. (2013). Climate change and waterborne diarrhoea in northern India: Impacts and adaptation strategies. *Science of The Total Environment*, *468–469*, S139–S151. https://doi.org/10.1016/j.scitotenv.2013.07.021

Mora, C., McKenzie, T., Gaw, I. M., Dean, J. M., von Hammerstein, H., Knudson, T. A., Setter, R. O., Smith, C. Z., Webster, K. M., Patz, J. A., & Franklin, E. C. (2022). Over half of known human pathogenic diseases can be aggravated by climate change. *Nature Climate Change*, *12*(9), Article 9. https://doi.org/10.1038/s41558-022-01426-1

Morato, T., González-Irusta, J.-M., Dominguez-Carrió, C., Wei, C.-L., Davies, A., Sweetman, A. K., Taranto, G. H., Beazley, L., García-Alegre, A., Grehan, A., Laffargue, P., Murillo, F. J., Sacau, M., Vaz, S., Kenchington, E., Arnaud-Haond, S., Callery, O., Chimienti, G., Cordes, E., … Carreiro-Silva, M. (2020). Climate-induced changes in the suitable habitat of cold-water corals and commercially important deep-sea fishes in the North Atlantic. *Global Change Biology*, *26*(4), 2181–2202. https://doi.org/10.1111/gcb.14996

Moravek, J. A., Andrews, L. R., Serota, M. W., Dorcy, J. A., Chapman, M., Wilkinson, C. E., Parker-Shames, P., Van Scoyoc, A., Verta, G., & Brashares, J. S. (2023). Centering 30 × 30 conservation initiatives on freshwater ecosystems. *Frontiers in Ecology and the Environment*, *21*(4), 199–206. https://doi.org/10.1002/fee.2573

Mordecai, E. A., Ryan, S. J., Caldwell, J. M., Shah, M. M., & LaBeaud, A. D. (2020). Climate change could shift disease burden from malaria to arboviruses in Africa. *The Lancet Planetary Health*, *4*(9), e416–e423. https://doi.org/10.1016/S2542-5196(20)30178-9

Morse, S. S., Mazet, J. A., Woolhouse, M., Parrish, C. R., Carroll, D., Karesh, W. B., Zambrana-Torrelio, C., Lipkin, W. I., & Daszak, P. (2012). Prediction and prevention of the next pandemic zoonosis. *The Lancet*, *380*(9857), 1956–1965. https://doi.org/10.1016/S0140-6736(12)61684-5

Mosnier, A., Javalera-Rincon, V., Jones, S. K., Andrew, R., Bai, Z., Baker, J., Basnet Kumar, S., Boer, R., Chavarro, J., Costa, W., Daloz, A. S., DeClerck, F. A., Diaz, M., Douzal, C., Howe Fan, A. C., Fetzer, I., Frank, F., Gonzalez-Abraham, C. E., Habiburrachman, A. H. F., … Zerriffi, H. (2023a). A decentralized approach to model national and global food and land use systems. *Environmental Research Letters*. https://doi.org/10.1088/1748-9326/acc044

Mosnier, A., Javalera-Rincon, V., Jones, S. K., Andrew, R., Bai, Z., Baker, J., Basnet, S., Boer, R., Chavarro, J., Costa, W., Daloz, A. S., DeClerck, F. A., Diaz, M., Douzal, C., Howe Fan, A. C., Fetzer, I., Frank, F., Gonzalez-Abraham, C. E., Habiburrachman, A. H. F., … Zerriffi, H. (2023b). A decentralized approach to model national and global food and land use systems. *Environmental Research Letters*, *18*(4), 045001. https://doi.org/10.1088/1748-9326/acc044

Mu, Y., Guo, Y., Li, X., Li, P., Bai, J., Linke, S., & Cui, B. (2022). Cost-effective integrated conservation and restoration priorities by trading off multiple ecosystem services. *Journal of Environmental Management*, *320*, 115915. https://doi.org/10.1016/j.jenvman.2022.115915

Navarro Garcia, J., Marcos-Martinez, R., Mosnier, A., Schmidt-Traub, G., Javalera Rincon, V., Obersteiner, M., Perez Guzman, K., Thomson, M. J., Penescu, L., Douzal, C., Bryan, B. A., & Hadjikakou, M. (2022). Multi-target scenario discovery to plan for sustainable food and land systems in Australia. *Sustainability Science*. https://doi.org/10.1007/s11625-022-01202-2

Navedo, J. G., Piersma, T., Figuerola, J., & Vansteelant, W. (2022). Spain's Doñana World Heritage Site in danger. *Science*, *376*(6589), 144–144. https://doi.org/10.1126/science.abo7363

Ng, V., Rees, E. E., Lindsay, L. R., Drebot, M. A., Brownstone, T., Sadeghieh, T., & Khan, S. U. (2019). Could exotic mosquito-borne diseases emerge in Canada with climate change? *Canada Communicable Disease Report = Releve Des Maladies Transmissibles Au Canada*, *45*(4), 98–107. https://doi.org/10.14745/ccdr.v45i04a04

Nnko, H. J., Gwakisa, P. S., Ngonyoka, A., Sindato, C., & Estes, A. B. (2021). Potential impacts of climate change on geographical distribution of three primary vectors of African Trypanosomiasis in Tanzania's Maasai Steppe: G. m. Morsitans, G. pallidipes and G. swynnertoni. *PLOS Neglected Tropical Diseases*, *15*(2), 1–17. https://doi.org/10.1371/journal.pntd.0009081

N'Yeurt, A. de R., Chynoweth, D. P., Capron, M. E., Stewart, J. R., & Hasan, M. A. (2012). Negative carbon *via* Ocean Afforestation. *Process Safety and Environmental Protection*, *90*(6), 467–474. https://doi.org/10.1016/j.psep.2012.10.008

Nyong, A., Adesina, F., & Osman Elasha, B. (2007). The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel. *Mitigation and Adaptation Strategies for Global Change*, *12*(5), 787–797. https://doi.org/10.1007/s11027-007-9099-0

Oberdorff, T. (2022). Time for decisive actions to protect freshwater ecosystems from global changes. *Knowledge & Management of Aquatic Ecosystems*, *423*, 19. https://doi.org/10.1051/kmae/2022017

Obura, D. O., DeClerck, F., Verburg, P. H., Gupta, J., Abrams, J. F., Bai, X., Bunn, S., Ebi, K. L., Gifford, L., Gordon, C., Jacobson, L., Lenton, T. M., Liverman, D., Mohamed, A., Prodani, K., Rocha, J. C., Rockström, J., Sakschewski, B., Stewart-Koster, B., … Zimm, C. (2023). Achieving a nature- and people-positive future. *One Earth*, *6*(2), 105–117. https://doi.org/10.1016/j.oneear.2022.11.013

Odgaard, M. V., Turner, K. G., Bøcher, P. K., Svenning, J.-C., & Dalgaard, T. (2017). A multi-criteria, ecosystem-service value method used to assess catchment suitability for potential wetland reconstruction in Denmark. *Ecological Indicators*, *77*, 151–165. https://doi.org/10.1016/j.ecolind.2016.12.001

Ojea, E., Lester, S. E., & Salgueiro-Otero, D. (2020). Adaptation of Fishing Communities to Climate-Driven Shifts in Target Species. *One Earth*, *2*(6), 544–556. https://doi.org/10.1016/j.oneear.2020.05.012

Okruszko, T., Duel, H., Acreman, M., Grygoruk, M., Flörke, M., & Schneider, C. (2011). Broad-scale ecosystem services of European wetlands—Overview of the current situation and future perspectives under different climate and water management scenarios. *Hydrological Sciences Journal*, *56*(8), 1501–1517. https://doi.org/10.1080/02626667.2011.631188

O'Neill, B. C., Kriegler, E., Ebi, K. L., Kemp-Benedict, E., Riahi, K., Rothman, D. S., Van Ruijven, B. J., Van Vuuren, D. P., Birkmann, J., Kok, K., Levy, M., & Solecki, W. (2017). The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. *Global Environmental Change*, *42*, 169–180. https://doi.org/10.1016/j.gloenvcha.2015.01.004

Otero, I., Rigal, S., Pereira, L. M., Kim, H., Gamboa, G., Tello, E., & Grêt-Regamey, A. (2022). *Degrowth scenarios for biodiversity? Some methodological steps and a call for collaboration* [Preprint]. SocArXiv. https://doi.org/10.31235/osf.io/fcvpd

Palacios-Abrantes, J., Badhe, R., Bamford, A., Cheung, W. W. L., Foden, W., Frazão Santos, C., Grey, K.-A., Kühn, N., Maciejewski, K., McGhie, H., Midgley, G. F., Smit, I. P. J., & Pereira, L. M. (2022). Managing biodiversity in the Anthropocene: Discussing the Nature Futures Framework as a tool for adaptive decision-making for nature under climate change. *Sustainability Science*. https://doi.org/10.1007/s11625-022-01200-4

Papadimitriou, L., Trnka, M., Harrison, P., & Holman, I. (2019). Cross-sectoral and trans-national interactions in national-scale climate change impacts assessment—The case of the Czech Republic. *Regional Environmental Change*, *19*(8), 2453–2464. https://doi.org/10.1007/s10113-019-01558-9

Parodi, A., Leip, A., De Boer, I. J. M., Slegers, P. M., Ziegler, F., Temme, E. H. M., Herrero, M., Tuomisto, H., Valin, H., Van Middelaar, C. E., Van Loon, J. J. A., & Van Zanten, H. H. E. (2018). The potential of future foods for sustainable and healthy diets. *Nature Sustainability*, *1*(12), Article 12. https://doi.org/10.1038/s41893-018-0189-7

Parry, I. M., Ritchie, P. D. L., & Cox, P. M. (2022). Evidence of localised Amazon rainforest dieback in CMIP6 models. *Earth System Dynamics*, *13*(4), 1667–1675. https://doi.org/10.5194/esd-13-1667-2022

Pascual, U., Balvanera, P., Anderson, C. B., Chaplin-Kramer, R., Christie, M., González-Jiménez, D., Martin, A., Raymond, C. M., Termansen, M., Vatn, A., Athayde, S., Baptiste, B., Barton, D. N., Jacobs, S., Kelemen, E., Kumar, R., Lazos, E., Mwampamba, T. H., Nakangu, B., … Zent, E. (2023). Diverse values of nature for sustainability. *Nature*, *620*(7975), 813–823. https://doi.org/10.1038/s41586-023-06406-9

Paul, S. K., & Routray, J. K. (2010). Flood proneness and coping strategies: The experiences of two villages in Bangladesh. *Disasters*, *34*(2), 489–508. https://doi.org/10.1111/j.1467-7717.2009.01139.x

Payet, R., & Obura, D. (2004). The Negative Impacts of Human Activities in the Eastern African Region: An International Waters Perspective. *AMBIO: A Journal of the Human Environment*, *33*(1), 24–33. https://doi.org/10.1579/0044-7447-33.1.24

Payne, M. R., Barange, M., Cheung, W. W. L., MacKenzie, B. R., Batchelder, H. P., Cormon, X., Eddy, T. D., Fernandes, J. A., Hollowed, A. B., Jones, M. C., Link, J. S., Neubauer, P., Ortiz, I., Queirós, A. M., & Paula, J. R. (2016). Uncertainties in projecting climate-change impacts in marine ecosystems. *ICES Journal of Marine Science*, *73*(5), 1272–1282. https://doi.org/10.1093/icesjms/fsv231

Pennino, M. G., Coll, M., Albo-Puigserver, M., Fernández-Corredor, E., Steenbeek, J., Giráldez, A., González, M., Esteban, A., & Bellido, J. M. (2020). Current and Future Influence of Environmental Factors on Small Pelagic Fish Distributions in the Northwestern Mediterranean Sea. *Frontiers in Marine Science*, *7*. https://doi.org/10.3389/fmars.2020.00622

Pereira, L. M., Davies, K. K., Den Belder, E., Ferrier, S., Karlsson-Vinkhuyzen, S., Kim, H., Kuiper, J. J., Okayasu, S., Palomo, M. G., Pereira, H. M., Peterson, G., Sathyapalan, J., Schoolenberg, M., Alkemade, R., Carvalho Ribeiro, S., Greenaway, A., Hauck, J., King, N., Lazarova, T., … Lundquist, C. J. (2020). Developing multiscale and integrative nature–people scenarios using the Nature Futures Framework. *People and Nature*, *2*(4), 1172–1195. https://doi.org/10.1002/pan3.10146

Pereira, L. M., Ortuño Crespo, G., Amon, D. J., Badhe, R., Bandeira, S., Bengtsson, F., Boettcher, M., Carmine, G., Cheung, W. W. L., Chibwe, B., Dunn, D., Gasalla, M. A., Halouani, G., Johnson, D. E., Jouffray, J.-B., Juri, S., Keys, P. W., Lübker, H. M., Merrie, A. S., … Zhou, W. (2023). The living infinite: Envisioning futures for transformed human-nature relationships on the high seas. *Marine Policy*, *153*, 105644. https://doi.org/10.1016/j.marpol.2023.105644

Perez-Guzman, K., Imanirareba, D., Jones, S. K., Neubauer, R., Niyitanga, F., & Naramabuye, F. X. (2022). Sustainability implications of Rwanda's Vision 2050 long-term development strategy. *Sustainability Science*, *18*(1), 485–499. https://doi.org/10.1007/s11625-022-01266-0

Perez-Guzman, K., Imanirareba, D., Jones, S. K., Neubauer, R., Niyitanga, F., & Naramabuye, F. X. (2023). Sustainability implications of Rwanda's Vision 2050 long-term development strategy. *Sustainability Science*, *18*(1), 485–499. https://doi.org/10.1007/s11625-022-01266-0

Perosa, F., Gelhaus, M., Zwirglmaier, V., Arias-Rodriguez, L. F., Zingraff-Hamed, A., Cyffka, B., & Disse, M. (2021). Integrated Valuation of Nature-Based Solutions Using TESSA: Three Floodplain Restoration Studies in the Danube Catchment. *Sustainability*, *13*(3), 1482. https://doi.org/10.3390/su13031482

Petza, D., Anastopoulos, P., Kalogirou, S., Coll, M., Garcia, S., Kaiser, M., Koukourouvli, N., Lourdi, I., Rice, J., Sciberras, M., & Katsanevakis, S. (2023). Contribution of area-based fisheries management measures to fisheries sustainability and marine conservation: A global scoping review. *Reviews in Fish Biology and Fisheries*, *33*(4), 1049–1073. https://doi.org/10.1007/s11160-023-09780-9

Petzold, J., Andrews, N., Ford, J. D., Hedemann, C., & Postigo, J. C. (2020). Indigenous knowledge on climate change adaptation: A global evidence map of academic literature. *Environmental Research Letters*, *15*(11), 113007. https://doi.org/10.1088/1748-9326/abb330

Pikaar, I., Matassa, S., Bodirsky, B. L., Weindl, I., Humpenöder, F., Rabaey, K., Boon, N., Bruschi, M., Yuan, Z., van Zanten, H., Herrero, M., Verstraete, W., & Popp, A. (2018). Decoupling Livestock from Land Use through Industrial Feed Production Pathways. *Environmental Science & Technology*, *52*(13), 7351–7359. https://doi.org/10.1021/acs.est.8b00216

Pinsky, M. L., Rogers, L. A., Morley, J. W., & Frölicher, T. L. (2020). Ocean planning for species on the move provides substantial benefits and requires few trade-offs. *Science Advances*, *6*(50), eabb8428. https://doi.org/10.1126/sciadv.abb8428

Piroddi, C., Akoglu, E., Andonegi, E., Bentley, J. W., Celić, I., Coll, M., Dimarchopoulou, D., Friedland, R., de Mutsert, K., Girardin, R., Garcia-Gorriz, E., Grizzetti, B., Hernvann, P.-Y., Heymans, J. J., Müller-Karulis, B., Libralato, S., Lynam, C. P., Macias, D., Miladinova, S., … Tsikliras, A. C. (2021). Effects of Nutrient Management Scenarios on Marine Food Webs: A Pan-European Assessment in Support of the Marine Strategy Framework Directive. *Frontiers in Marine Science*, *8*, 596797. https://doi.org/10.3389/fmars.2021.596797

Pittock, J., Finlayson, M., Arthington, A. H., Roux, D., Matthews, J. H., Biggs, H., Harrison, I., Blom, E., Flitcroft, R., Froend, R., Hermoso, V, Junk, W, Kumar, R, Linke, S, Nel, J, Nunes Da Cunha, C, Pattnaik, A, Pollard, S, Rast, W, … Viers, J. (2015). Managing freshwater, river, wetland and estuarine protected areas. In *Protected area governance and management* (pp. 569–608). ANU Press. https://www.jstor.org/stable/pdf/j.ctt1657v5d.26.pdf

PNCIMA Initiative. (2017, February 14). *Pacific north coast integrated management area plan*. Fisheries and Oceans Canada. https://www.dfo-mpo.gc.ca/oceans/publications/pncima-zgicnp/page01-eng.html

Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. *Science*, *360*(6392), 987–992. https://doi.org/10.1126/science.aaq0216

Popp, A., Calvin, K., Fujimori, S., Havlik, P., Humpenöder, F., Stehfest, E., Bodirsky, B. L., Dietrich, J. P., Doelmann, J. C., Gusti, M., Hasegawa, T., Kyle, P., Obersteiner, M., Tabeau, A., Takahashi, K., Valin, H., Waldhoff, S., Weindl, I., Wise, M., … Vuuren, D. P. van. (2017). Land-use futures in the shared socio-economic pathways. *Global Environmental Change*, *42*, 331–345. https://doi.org/10.1016/j.gloenvcha.2016.10.002

Pörtner, H.-O., Scholes, R. J., Agard, J., Archer, E., Arneth, A., Bai, X., Barnes, D., Burrows, M., Chan, L., Cheung, W. L. (William), Diamond, S., Donatti, C., Duarte, C., Eisenhauer, N., Foden, W., Gasalla, M. A., Handa, C., Hickler, T., Hoegh-Guldberg, O., … Ngo, H. (2021a). *Scientific outcome of the IPBES-IPCC co-sponsored workshop on biodiversity and climate change* (Version 5). Zenodo. https://doi.org/10.5281/zenodo.5101125

Pörtner, H.-O., Scholes, R. J., Agard, J., Archer, E., Bai, X., Barnes, D., Burrows, M., Chan, L., Cheung, W. L. (William), Diamond, S., Donatti, C., Duarte, C., Eisenhauer, N., Foden, W., Gasalla, M. A., Handa, C., Hickler, T., Hoegh-Guldberg, O., Ichii, K., … Ngo, H. (2021b). *IPBES-IPCC co-sponsored workshop report on biodiversity and climate change*. Zenodo. https://doi.org/10.5281/zenodo.5101133

Pörtner, H.-O., Scholes, R. J., Arneth, A., Barnes, D. K. A., Burrows, M. T., Diamond, S. E., Duarte, C. M., Kiessling, W., Leadley, P., Managi, S., McElwee, P., Midgley, G., Ngo, H. T., Obura, D., Pascual, U., Sankaran, M., Shin, Y. J., & Val, A. L. (2023). Overcoming the coupled climate and biodiversity crises and their societal impacts. *Science*, *380*(6642), eabl4881. https://doi.org/10.1126/science.abl4881

Prudhomme, R., Palma, A. D., Dumas, P., Gonzalez, R., Leadley, P., Levrel, H., Purvis, A., & Brunelle, T. (2020). Combining mitigation strategies to increase co-benefits for biodiversity and food security. *Environmental Research Letters*, *15*(11), 114005. https://doi.org/10.1088/1748-9326/abb10a

Pudar, R., Plavšić, J., & Todorović, A. (2020). Evaluation of Green and Grey Flood Mitigation Measures in Rural Watersheds. *Applied Sciences*, *10*(19), 6913. https://doi.org/10.3390/app10196913

Rabin, S. S., Alexander, P., Henry, R., Anthoni, P., Pugh, T. A. M., Rounsevell, M. D. A., & Arneth, A. (2020). Impacts of future agricultural change on ecosystem service indicators. *Earth System Dynamics*, *11*(2), 357–376. https://doi.org/10.5194/esd-11-357-2020

Rana, S., Ávila-García, D., Dib, V., Familia, L., Gerhardinger, L. C., Martin, E., Martins, P. I., Pompeu, J., Selomane, O., Tauli, J. I., Tran, D. H. T., Valle, M., Von Below, J., & Pereira, L. M. (2020). The voices of youth in envisioning positive futures for nature and people. *Ecosystems and People*, *16*(1), 326–344. https://doi.org/10.1080/26395916.2020.1821095

Rasche, L., Habel, J. C., Stork, N., Schmid, E., & Schneider, U. A. (2022). Food *versus* wildlife: Will biodiversity hotspots benefit from healthier diets? *Global Ecology and Biogeography*, *31*(6), 1090–1103. https://doi.org/10.1111/geb.13485

Rasche, L., Schneider, U. A., & Steinhauser, J. (2022a). A stakeholders' pathway towards a future land use and food system in Germany. *Sustainability Science*. https://doi.org/10.1007/s11625-022-01212-0

Rasche, L., Schneider, U. A., & Steinhauser, J. (2022b). A stakeholders' pathway towards a future land use and food system in Germany. *Sustainability Science*. https://doi.org/10.1007/s11625-022-01212-0

Raymond, C. M., Anderson, C. B., Athayde, S., Vatn, A., Amin, A. M., Arias-Arévalo, P., Christie, M., Cantú-Fernández, M., Gould, R. K., Himes, A., Kenter, J. O., Lenzi, D., Muraca, B., Murali, R., O'Connor, S., Pascual, U., Sachdeva, S., Samakov, A., & Zent, E. (2023). An inclusive typology of values for navigating transformations towards a just and sustainable future. *Current Opinion in Environmental Sustainability*, *64*, 101301. https://doi.org/10.1016/j.cosust.2023.101301

Reid, A. J., Young, N., Hinch, S. G., & Cooke, S. J. (2022). Learning from Indigenous knowledge holders on the state and future of wild Pacific salmon. *FACETS*, *7*, 718–740. https://doi.org/10.1139/facets-2021-0089

Reinhardt, J., Liersch, S., Abdeladhim, M. A., Diallo, M., Dickens, C., Fournet, S., Hattermann, F. F., Kabaseke, C., Muhumuza, M., Mul, M. L., Pilz, T., Otto, I. M., & Walz, A. (2018). Systematic evaluation of scenario assessments supporting sustainable integrated natural resources management: Evidence from four case studies in Africa. *Ecology and Society*, *23*(1), art5. https://doi.org/10.5751/ES-09728-230105

Reynard, N., Ellison, E., Wilson, A., Williamson, P., O-Niles, J., Ransome, D. E., & Mashayek, D. A. (n.d.). *The contribution of coastal blue carbon ecosystems to climate change mitigation and adaptation*. Grantham Institute, Imperial College London. https://doi.org/10.25561/84458

Rocklöv, J., Semenza, J. C., Dasgupta, S., Robinson, E. J. Z., Abd El Wahed, A., Alcayna, T., Arnés-Sanz, C., Bailey, M., Bärnighausen, T., Bartumeus, F., Borrell, C., Bouwer, L. M., Bretonnière, P.-A., Bunker, A., Chavardes, C., Van Daalen, K. R., Encarnação, J., González-Reviriego, N., Guo, J., … De Roode, S. (2023). Decision-support tools to build climate resilience against emerging infectious diseases in Europe and beyond. *The Lancet Regional Health – Europe*, *32*, 100701. https://doi.org/10.1016/j.lanepe.2023.100701

Rockström, J., Falkenmark, M., Allan, T., Folke, C., Gordon, L., Jägerskog, A., Kummu, M., Lannerstad, M., Meybeck, M., Molden, D., Postel, S., Savenije, H. H. G., Svedin, U., Turton, A., & Varis, O. (2014). The unfolding water drama in the Anthropocene: Towards a resilience-based perspective on water for global sustainability. *Ecohydrology*, *7*(5), 1249–1261. https://doi.org/10.1002/eco.1562

Roe, S., Streck, C., Obersteiner, M., Frank, S., Griscom, B., Drouet, L., Fricko, O., Gusti, M., Harris, N., Hasegawa, T., Hausfather, Z., Havlík, P., House, J., Nabuurs, G.-J., Popp, A., Sánchez, M. J. S., Sanderman, J., Smith, P., Stehfest, E., & Lawrence, D. (2019). Contribution of the land sector to a 1.5 °C world. *Nature Climate Change*, *9*(11), 817–828. https://doi.org/10.1038/s41558-019-0591-9

Rohr, J. R., Civitello, D. J., Halliday, F. W., Hudson, P. J., Lafferty, K. D., Wood, C. L., & Mordecai, E. A. (2020). Towards common ground in the biodiversity–disease debate. *Nature Ecology & Evolution*, *4*(1), Article 1. https://doi.org/10.1038/s41559-019-1060-6

Romanello, M., Di Napoli, C., Drummond, P., Green, C., Kennard, H., Lampard, P., Scamman, D., Arnell, N., Ayeb-Karlsson, S., Ford, L. B., Belesova, K., Bowen, K., Cai, W., Callaghan, M., Campbell-Lendrum, D., Chambers, J., van Daalen, K. R., Dalin, C., Dasandi, N., … Costello, A. (2022). The 2022 report of the Lancet Countdown on health and climate change: Health at the mercy of fossil fuels. *The Lancet*, *400*(10363), 1619–1654. https://doi.org/10.1016/S0140-6736(22)01540-9

Rong, Q., Zeng, J., Su, M., Yue, W., Xu, C., & Cai, Y. (2021). Management optimization of nonpoint source pollution considering the risk of exceeding criteria under uncertainty. *Science of The Total Environment*, *758*, 143659. https://doi.org/10.1016/j.scitotenv.2020.143659

Rosegrant, M. W., Ringler, C., & Zhu, T. (2009). Water for Agriculture: Maintaining Food Security under Growing Scarcity. *Annual Review of Environment and Resources*, *34*(1), 205–222. https://doi.org/10.1146/annurev.environ.030308.090351

Ross, F. W. R., Boyd, P. W., Filbee-Dexter, K., Watanabe, K., Ortega, A., Krause-Jensen, D., Lovelock, C., Sondak, C. F. A., Bach, L. T., Duarte, C. M., Serrano, O., Beardall, J., Tarbuck, P., & Macreadie, P. I. (2023). Potential role of seaweeds in climate change mitigation. *Science of The Total Environment*, *885*, 163699. https://doi.org/10.1016/j.scitotenv.2023.163699

Rounsevell, M. D. A., Arneth, A., Brown, C., Cheung, W. W. L., Gimenez, O., Holman, I., Leadley, P., Luján, C., Mahevas, S., Maréchaux, I., Pélissier, R., Verburg, P. H., Vieilledent, G., Wintle, B. A., & Shin, Y.-J. (2021). Identifying uncertainties in scenarios and models of socio-ecological systems in support of decision-making. *One Earth*, *4*(7), 967–985. https://doi.org/10.1016/j.oneear.2021.06.003

Rulli, M. C., Bellomi, D., Cazzoli, A., De Carolis, G., & D'Odorico, P. (2016). The water-land-food nexus of first-generation biofuels. *Scientific Reports*, *6*(1), 22521. https://doi.org/10.1038/srep22521

Rulli, M. C., D'Odorico, P., Galli, N., & Hayman, D. T. S. (2021). Land-use change and the livestock revolution increase the risk of zoonotic coronavirus transmission from rhinolophid bats. *Nature Food*, *2*(6), Article 6. https://doi.org/10.1038/s43016-021-00285-x

Saah, D., Patterson, T., Buchholz, T., Ganz, D., Albert, D., & Rush, K. (2014). Modeling economic and carbon consequences of a shift to wood-based energy in a rural 'cluster'; a network analysis in southeast Alaska. *Ecological Economics*, *107*, 287–298. https://doi.org/10.1016/j.ecolecon.2014.08.011

Sala, E., Mayorga, J., Bradley, D., Cabral, R. B., Atwood, T. B., Auber, A., Cheung, W., Costello, C., Ferretti, F., Friedlander, A. M., Gaines, S. D., Garilao, C., Goodell, W., Halpern, B. S., Hinson, A., Kaschner, K., Kesner-Reyes, K., Leprieur, F., McGowan, J., … Lubchenco, J. (2021). Protecting the global ocean for biodiversity, food and climate. *Nature*, *592*(7854), 397–402. https://doi.org/10.1038/s41586-021-03371-z

Samy, A. M., Yáñez-Arenas, C., Jaeschke, A., Cheng, Y., & Thomas, S. M. (2022). Modeling Distributional Potential of Infectious Diseases. In F. S. Faruque (Ed.), *Geospatial Technology for Human Well-Being and Health* (pp. 337–353). Springer International Publishing. https://doi.org/10.1007/978-3-030-71377-5_18

Sarkar, P., Salami, M., Githiora, Y., Vieira, R., Navarro, A., Clavijo, D., & Padgurschi, M. (2020). A conceptual model to understand the drivers of change in tropical wetlands: A comparative assessment in India and Brazil. *Biota Neotropica*, *20*(suppl 1), e20190913. https://doi.org/10.1590/1676-0611-bn-2019-0913

Sarkki, S., Pihlajamäki, M., Rasmus, S., & Eronen, J. T. (2023). "Rights for Life" scenario to reach biodiversity targets and social equity for indigenous peoples and local communities. *Biological Conservation*, *280*, 109958. https://doi.org/10.1016/j.biocon.2023.109958

Saunders, M. I., Bode, M., Atkinson, S., Klein, C. J., Metaxas, A., Beher, J., Beger, M., Mills, M., Giakoumi, S., Tulloch, V., & Possingham, H. P. (2017). Simple rules can guide whether land- or ocean-based conservation will best benefit marine ecosystems. *PLOS Biology*, *15*(9), e2001886. https://doi.org/10.1371/journal.pbio.2001886

Saunders, M. I., Doropoulos, C., Bayraktarov, E., Babcock, R. C., Gorman, D., Eger, A. M., Vozzo, M. L., Gillies, C. L., Vanderklift, M. A., Steven, A. D. L., Bustamante, R. H., & Silliman, B. R. (2020). Bright Spots in Coastal Marine Ecosystem Restoration. *Current Biology*, *30*(24), R1500–R1510. https://doi.org/10.1016/j.cub.2020.10.056

Scharlemann, J. P. W., Brock, R. C., Balfour, N., Brown, C., Burgess, N. D., Guth, M. K., Ingram, D. J., Lane, R., Martin, J. G. C., Wicander, S., & Kapos, V. (2020). Towards understanding interactions between Sustainable Development Goals: The role of environment–human linkages. *Sustainability Science*, *15*(6), 1573–1584. https://doi.org/10.1007/s11625-020-00799-6

Schewe, J., Heinke, J., Gerten, D., Haddeland, I., Arnell, N. W., Clark, D. B., Dankers, R., Eisner, S., Fekete, B. M., Colón-González, F. J., Gosling, S. N., Kim, H., Liu, X., Masaki, Y., Portmann, F. T., Satoh, Y., Stacke, T., Tang, Q., Wada, Y., … Kabat, P. (2014). Multimodel assessment of water scarcity under climate change. *Proceedings of the National Academy of Sciences*, *111*(9), 3245–3250. https://doi.org/10.1073/pnas.1222460110

Schlingmann, A., Graham, S., Benyei, P., Corbera, E., Sanesteban, I. M., Marelle, A., Soleymani-Fard, R., & Reyes-García, V. (2021). Global patterns of adaptation to climate change by Indigenous Peoples and local communities. A systematic review. *Current Opinion in Environmental Sustainability*, *51*, 55–64. https://doi.org/10.1016/j.cosust.2021.03.002

Seddon, N. (2022). Harnessing the potential of nature-based solutions for mitigating and adapting to climate change. *Science*, *376*(6600), 1410–1416. https://doi.org/10.1126/science.abn9668

Seddon, N., Smith, A., Smith, P., Key, I., Chausson, A., Girardin, C., House, J., Srivastava, S., & Turner, B. (2021). Getting the message right on nature-based solutions to climate change. *Global Change Biology*, *27*(8), 1518–1546. https://doi.org/10.1111/gcb.15513

Shin, Y.-J., Midgley, G. F., Archer, E. R. M., Arneth, A., Barnes, D. K. A., Chan, L., Hashimoto, S., Hoegh-Guldberg, O., Insarov, G., Leadley, P., Levin, L. A., Ngo, H. T., Pandit, R., Pires, A. P. F., Pörtner, H.-O., Rogers, A. D., Scholes, R. J., Settele, J., & Smith, P. (2022). Actions to halt biodiversity loss generally benefit the climate. *Global Change Biology*, *28*(9), 2846–2874. https://doi.org/10.1111/gcb.16109

Siegel, D. A., DeVries, T., Cetinić, I., & Bisson, K. M. (2023). Quantifying the Ocean's Biological Pump and Its Carbon Cycle Impacts on Global Scales. *Annual Review of Marine Science*, *15*(1), 329–356. https://doi.org/10.1146/annurev-marine-040722-115226

Sikkema, R. S., Begeman, L., Janssen, R., Wolters, W. J., Geurtsvankessel, C., De Bruin, E., Hakze-van Der Honing, R. W., Eblé, P., Van Der Poel, W. H. M., Van Den Brand, J. M. A., Slaterus, R., La Haye, M., Koopmans, M. P. G., Velkers, F., & Kuiken, T. (2022). Risks of SARS-CoV-2 transmission between free-ranging animals and captive mink in the Netherlands. *Transboundary and Emerging Diseases*, *69*(6), 3339–3349. https://doi.org/10.1111/tbed.14686

Silliman, B. R., Angelini, C., Krause, G., Saunders, M. I., Smith, C. S., Valdez, S. R., McLean, J. E. T., Paxton, A. B., Heide, T. van der, & Abelson, A. (2023). Editorial: Marine ecosystem restoration (MER) – a call for a more inclusive paradigm. *Frontiers in Marine Science*, *10*. https://doi.org/10.3389/fmars.2023.1250022

Silva, R. F. B. da, Millington, J. D. A., Vina, A., Dou, Y., Moran, E., Batistella, M., Lapola, D. M., & Liu, J. (2023). Balancing food production with climate change mitigation and biodiversity conservation in the Brazilian Amazon. *The Science of the Total Environment*, *904*, 166681. https://doi.org/10.1016/j.scitotenv.2023.166681

Simkin, R. D., Seto, K. C., McDonald, R. I., & Jetz, W. (2022). Biodiversity impacts and conservation implications of urban land expansion projected to 2050. *Proceedings of the National Academy of Sciences*, *119*(12), e2117297119. https://doi.org/10.1073/pnas.2117297119

Sitas, N., Harmáčková, Z., Anticamara, J., Arneth, A., Badola, R., Biggs, R., Blanchard, R., Brotons, L., Cantele, M., Coetzer, K., DasGupta, R., den Belder, E., Ghosh, S., Guisan, A., Gundimeda, H., Hamann, M., Harrison, P. A., Hashimoto, S., Hauck, J., … Valle, M. (2019). Exploring the usefulness of scenario archetypes in science-policy processes: Experience across IPBES assessments. *Ecology and Society*, *24*(3). https://doi.org/10.5751/ES-11039-240335

Skoulikaris, C., Makris, C., Katirtzidou, M., Baltikas, V., & Krestenitis, Y. (2021). Assessing the Vulnerability of a Deltaic Environment due to Climate Change Impact on Surface and Coastal Waters: The Case of Nestos River (Greece). *Environmental Modeling & Assessment*, *26*(4), 459–486. https://doi.org/10.1007/s10666-020-09746-2

Sloat, L. L., Davis, S. J., Gerber, J. S., Moore, F. C., Ray, D. K., West, P. C., & Mueller, N. D. (2020). Climate adaptation by crop migration. *Nature Communications*, *11*(1), 1243. https://doi.org/10.1038/s41467-020-15076-4

Smith, A. C., Harrison, P. A., Leach, N. J., Godfray, H. C. J., Hall, J. W., Jones, S. M., Gall, S. S., & Obersteiner, M. (2023). Sustainable pathways towards climate and biodiversity goals in the UK: The importance of managing land-use synergies and trade-offs. *Sustainability Science*, *18*(1), Article 1. https://doi.org/10.1007/s11625-022-01242-8

Smith, K., Woodward, A., Campbell-Lendrum, D., Chadee, D., Honda, Y., Liu, Q., Olwoch, J., Revich, B., Sauerborn, R., Aranda, C., & others. (2014). Human health: Impacts, adaptation, and co-benefits. In *Climate Change 2014: Impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the fifth assessment report of the Intergovernmental Panel on Climate Change* (pp. 709–754). Cambridge University Press. https://doi.org/10.1017/CBO9781107415379.016

Smith, P., Arneth, A., Barnes, D. K. A., Ichii, K., Marquet, P. A., Popp, A., Pörtner, H.-O., Rogers, A. D., Scholes, R. J., Strassburg, B., Wu, J., & Ngo, H. (2022). How do we best synergize climate mitigation actions to co-benefit biodiversity? *Global Change Biology*, *28*(8), 2555–2577. https://doi.org/10.1111/gcb.16056

Smith, P., Calvin, K., Nkem, J., Campbell, D., Cherubini, F., Grassi, G., Korotkov, V., Le Hoang, A., Lwasa, S., McElwee, P., Nkonya, E., Saigusa, N., Soussana, J.-F., Taboada, M. A., Manning, F. C., Nampanzira, D., Arias-Navarro, C., Vizzarri, M., House, J., … Arneth, A. (2020). Which practices co-deliver food security, climate change mitigation and adaptation, and combat land degradation and desertification? *Global Change Biology*, *26*(3), 1532–1575. https://doi.org/10.1111/gcb.14878

Soergel, B., Kriegler, E., Weindl, I., Rauner, S., Dirnaichner, A., Ruhe, C., Hofmann, M., Bauer, N., Bertram, C., Bodirsky, B. L., Leimbach, M., Leininger, J., Levesque, A., Luderer, G., Pehl, M., Wingens, C., Baumstark, L., Beier, F., Dietrich, J. P., … Popp, A. (2021). A sustainable development pathway for climate action within the UN 2030 Agenda. *Nature Climate Change*, *11*(8), 656–664. https://doi.org/10.1038/s41558-021-01098-3

Sokolow, S. H., Jones, I. J., Jocque, M., La, D., Cords, O., Knight, A., Lund, A., Wood, C. L., Lafferty, K. D., Hoover, C. M., Collender, P. A., Remais, J. V., Lopez-Carr, D., Fisk, J., Kuris, A. M., & De Leo, G. A. (2017). Nearly 400 million people are at higher risk of schistosomiasis because dams block the migration of snail-eating river prawns. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *372*(1722), 20160127. https://doi.org/10.1098/rstb.2016.0127

Soto-Navarro, C. A., Harfoot, M., Hill, S. L. L., Campbell, J., Mora, F., Campos, C., Pretorius, C., Pascual, U., Kapos, V., Allison, H., & Burgess, N. D. (2021). Towards a multidimensional biodiversity index for national application. *Nature Sustainability*, *4*(11), 933–942. https://doi.org/10.1038/s41893-021-00753-z

Springmann, M., Clark, M., Mason-D’Croz, D., Wiebe, K., Bodirsky, B. L., Lassaletta, L., de Vries, W., Vermeulen, S. J., Herrero, M., Carlson, K. M., Jonell, M., Troell, M., DeClerck, F., Gordon, L. J., Zurayk, R., Scarborough, P., Rayner, M., Loken, B., Fanzo, J., … Willett, W. (2018). Options for keeping the food system within environmental limits. *Nature*, *562*(7728), Article 7728. https://doi.org/10.1038/s41586-018-0594-0

Springmann, M., Wiebe, K., Mason-D’Croz, D., Sulser, T. B., Rayner, M., & Scarborough, P. (2018). Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: A global modelling analysis with country-level detail. *The Lancet. Planetary Health*, *2*(10), e451–e461. https://doi.org/10.1016/S2542-5196(18)30206-7

Staccione, A., Brown, C., Arneth, A., Rounsevell, M., Hrast Essenfelder, A., Seo, B., & Mysiak, J. (2023). Exploring the effects of protected area networks on the European land system. *Journal of Environmental Management*, *337*, 117741. https://doi.org/10.1016/j.jenvman.2023.117741

Steel, J. R., Atlas, W. I., Ban, N. C., Wilson, K., Wilson, J., Housty, W. G., & Moore, J. W. (2021). Understanding barriers, access, and management of marine mixed-stock fisheries in an era of reconciliation: Indigenous-led salmon monitoring in British Columbia. *FACETS*, *6*, 592–613. https://doi.org/10.1139/facets-2020-0080

Steenbeek, J., Buszowski, J., Chagaris, D., Christensen, V., Coll, M., Fulton, E. A., Katsanevakis, S., Lewis, K. A., Mazaris, A. D., Macias, D., De Mutsert, K., Oldford, G., Pennino, M. G., Piroddi, C., Romagnoni, G., Serpetti, N., Shin, Y.-J., Spence, M. A., & Stelzenmüller, V. (2021). Making spatial-temporal marine ecosystem modelling better – A perspective. *Environmental Modelling & Software*, *145*, 105209. https://doi.org/10.1016/j.envsoft.2021.105209

Stolton, S., Dudley, N., Avcıoğlu Çokçalışkan, B., Hunter, D., Ivanić, K., Kanga, E., Kettunen, M., Kumagai, Y., Maxted, N., Senior, J., Wong, M, Keenleyside, K., Mulrooney, D., & Waithaka, J. (2015). Values and benefits of protected areas. In *Protected Area Governance and Management* (pp. 145–168). ANU Press. https://www.jstor.org/stable/pdf/j.ctt1657v5d.13.pdf

Strassburg, B. B. N., Beyer, H. L., Crouzeilles, R., Iribarrem, A., Barros, F., de Siqueira, M. F., Sánchez-Tapia, A., Balmford, A., Sansevero, J. B. B., Brancalion, P. H. S., Broadbent, E. N., Chazdon, R. L., Filho, A. O., Gardner, T. A., Gordon, A., Latawiec, A., Loyola, R., Metzger, J. P., Mills, M., … Uriarte, M. (2019). Strategic approaches to restoring ecosystems can triple conservation gains and halve costs. *Nature Ecology & Evolution*, *3*(1), 62–70. https://doi.org/10.1038/s41559-018-0743-8

Strassburg, B. B. N., Iribarrem, A., Beyer, H. L., Cordeiro, C. L., Crouzeilles, R., Jakovac, C. C., Braga Junqueira, A., Lacerda, E., Latawiec, A. E., Balmford, A., Brooks, T. M., Butchart, S. H. M., Chazdon, R. L., Erb, K.-H., Brancalion, P., Buchanan, G., Cooper, D., Díaz, S., Donald, P. F., … Visconti, P. (2020). Global priority areas for ecosystem restoration. *Nature*, *586*(7831), Article 7831. https://doi.org/10.1038/s41586-020-2784-9

Strefler, J., Bauer, N., Kriegler, E., Popp, A., Giannousakis, A., & Edenhofer, O. (2018). Between Scylla and Charybdis: Delayed mitigation narrows the passage between large-scale CDR and high costs. *Environmental Research Letters*, *13*(4), 044015. https://doi.org/10.1088/1748-9326/aab2ba

Stronge, D. C., Kannemeyer, R. L., Harmsworth, G. R., & Stevenson, B. A. (2023). Achieving soil health in Aotearoa New Zealand through a pluralistic values-based framework: Mauri ora ki te whenua, mauri ora ki te tangata. *Sustainability Science*. https://doi.org/10.1007/s11625-022-01269-x

Taffarello, D., Calijuri, M. do C., Viani, R. A. G., Marengo, J. A., & Mendiondo, E. M. (2017). Hydrological services in the Atlantic Forest, Brazil: An ecosystem-based adaptation using ecohydrological monitoring. *Climate Services*, *8*, 1–16. https://doi.org/10.1016/j.cliser.2017.10.005

Tallis, H. M., Hawthorne, P. L., Polasky, S., Reid, J., Beck, M. W., Brauman, K., Bielicki, J. M., Binder, S., Burgess, M. G., Cassidy, E., Clark, A., Fargione, J., Game, E. T., Gerber, J., Isbell, F., Kiesecker, J., McDonald, R., Metian, M., Molnar, J. L., … McPeek, B. (2018). An attainable global vision for conservation and human well- being. *Frontiers in Ecology and the Environment*, *16*(10), 563–570. https://doi.org/10.1002/fee.1965

Tengö, M., Brondizio, E. S., Elmqvist, T., Malmer, P., & Spierenburg, M. (2014). Connecting Diverse Knowledge Systems for Enhanced Ecosystem Governance: The Multiple Evidence Base Approach. *AMBIO*, *43*(5), 579–591. https://doi.org/10.1007/s13280-014-0501-3

Tengö, M., Darriet, L., Gebeyehu, F., Gebremariam, G., Kamau, E., Kinya, J., Malmer, P., Megersa, A., Mitambo, S., Muriuki, M., Mwongera, V., & Oussou Lio, A. (2021). *Indigenous futures thinking: Changing the narrative and re-building based on re-rooting*. SwedBio at Stockholm Resilience Centre.

Theurl, M. C., Lauk, C., Kalt, G., Mayer, A., Kaltenegger, K., Morais, T. G., Teixeira, R. F. M., Domingos, T., Winiwarter, W., Erb, K.-H., & Haberl, H. (2020). Food systems in a zero-deforestation world: Dietary change is more important than intensification for climate targets in 2050. *Science of The Total Environment*, *735*, 139353. https://doi.org/10.1016/j.scitotenv.2020.139353

Thompson, J. R., Gosling, S. N., Zaherpour, J., & Laizé, C. L. R. (2021). Increasing Risk of Ecological Change to Major Rivers of the World With Global Warming. *Earth's Future*, *9*(11). https://doi.org/10.1029/2021EF002048

Thornton, P., Gurney-Smith, H., & Wollenberg, E. (2023). Alternative sources of protein for food and feed. *Current Opinion in Environmental Sustainability*, *62*, 101277. https://doi.org/10.1016/j.cosust.2023.101277

Tickner, D., Opperman, J. J., Abell, R., Acreman, M., Arthington, A. H., Bunn, S. E., Cooke, S. J., Dalton, J., Darwall, W., Edwards, G., Harrison, I., Hughes, K., Jones, T., Leclère, D., Lynch, A. J., Leonard, P., McClain, M. E., Muruven, D., Olden, J. D., … Young, L. (2020). Bending the Curve of Global Freshwater Biodiversity Loss: An Emergency Recovery Plan. *BioScience*, *70*(4), 330–342. https://doi.org/10.1093/biosci/biaa002

Tittensor, D. P., Novaglio, C., Harrison, C. S., Heneghan, R. F., Barrier, N., Bianchi, D., Bopp, L., Bryndum-Buchholz, A., Britten, G. L., Büchner, M., Cheung, W. W. L., Christensen, V., Coll, M., Dunne, J. P., Eddy, T. D., Everett, J. D., Fernandes-Salvador, J. A., Fulton, E. A., Galbraith, E. D., … Blanchard, J. L. (2021). Next-generation ensemble projections reveal higher climate risks for marine ecosystems. *Nature Climate Change*, *11*(11), 973–981. https://doi.org/10.1038/s41558-021-01173-9

Tjaden, N. B., Caminade, C., Beierkuhnlein, C., & Thomas, S. M. (2018). Mosquito-Borne Diseases: Advances in Modelling Climate-Change Impacts. *Trends in Parasitology*, *34*(3), 227–245. https://doi.org/10.1016/j.pt.2017.11.006

Tjaden, N. B., Cheng, Y., Beierkuhnlein, C., & Thomas, S. M. (2021). Chikungunya Beyond the Tropics: Where and When Do We Expect Disease Transmission in Europe? *Viruses*, *13*(6), 1024. https://doi.org/10.3390/v13061024

Tomscha, S. A., Bentley, S., Platzer, E., Jackson, B., De Roiste, M., Hartley, S., Norton, K., & Deslippe, J. R. (2021). Multiple methods confirm wetland restoration improves ecosystem services. *Ecosystems and People*, *17*(1), 25–40. https://doi.org/10.1080/26395916.2020.1863266

Tuninetti, M., Ridolfi, L., & Laio, F. (2022). Compliance with EAT–Lancet dietary guidelines would reduce global water footprint but increase it for 40 per cent of the world population. *Nature Food*, *3*(2), 143–151. https://doi.org/10.1038/s43016-021-00452-0

Turner, N. J., & Reid, A. J. (2022). "When the Wild Roses Bloom": Indigenous Knowledge and Environmental Change in Northwestern North America. *GeoHealth*, *6*(11), e2022GH000612. https://doi.org/10.1029/2022GH000612

UNEP. (2021). *From Pollution to Solution: A global assessment of marine litter and plastic pollution. Synthesis*. United Nations Environment Programme. https://malaysia.un.org/sites/default/files/2022-02/POLSOLSum_1.pdf

UNEP. (2023). *UN Decade on Ecosystem Restoration*. https://www.unep.org/interactive/flagship-initiatives-boosting-nature-livelihoods/#1

UNEP-WCMC & IUCN. (2023a). *Protected Planet: The World Database on Other Effective Area-based Conservation Measures (WD-OECM)* (Version September 2023) [Dataset]. www.protectedplanet.net

UNEP-WCMC & IUCN. (2023b). *Protected Planet: The World Database on Protected Areas (WDPA)* (Version September 2023) [Dataset]. www.protectedplanet.net

Valin, H., Sands, R. D., Van Der Mensbrugghe, D., Nelson, G. C., Ahammad, H., Blanc, E., Bodirsky, B., Fujimori, S., Hasegawa, T., Havlik, P., Heyhoe, E., Kyle, P., Mason-D'Croz, D., Paltsev, S., Rolinski, S., Tabeau, A., Van Meijl, H., Von Lampe, M., & Willenbockel, D. (2014). The future of food demand: Understanding differences in global economic models. *Agricultural Economics*, *45*(1), 51–67. https://doi.org/10.1111/agec.12089

Van Dijk, M., Morley, T., Rau, M. L., & Saghai, Y. (2021). A meta-analysis of projected global food demand and population at risk of hunger for the period 2010–2050. *Nature Food*, *2*(7), 494–501. https://doi.org/10.1038/s43016-021-00322-9

van Meijl, H., Havlik, P., Lotze-Campen, H., Stehfest, E., Witzke, P., Domínguez, I. P., Bodirsky, B. L., van Dijk, M., Doelman, J., Fellmann, T., Humpenöder, F., Koopman, J. F. L., Müller, C., Popp, A., Tabeau, A., Valin, H., & van Zeist, W.-J. (2018). Comparing impacts of climate change and mitigation on global agriculture by 2050. *Environmental Research Letters*, *13*(6), 064021. https://doi.org/10.1088/1748-9326/aabdc4

van Rees, C. B., Waylen, K. A., Schmidt-Kloiber, A., Thackeray, S. J., Kalinkat, G., Martens, K., Domisch, S., Lillebø, A. I., Hermoso, V., Grossart, H., Schinegger, R., Decleer, K., Adriaens, T., Denys, L., Jarić, I., Janse, J. H., Monaghan, M. T., De Wever, A., Geijzendorffer, I., … Jähnig, S. C. (2020). Safeguarding freshwater life beyond 2020: Recommendations for the new global biodiversity framework from the European experience. *Conservation Letters*, *April*, 1–17. https://doi.org/10.1111/conl.12771

van Soest, H. L., van Vuuren, D. P., Hilaire, J., Minx, J. C., Harmsen, M. J. H. M., Krey, V., Popp, A., Riahi, K., & Luderer, G. (2019). Analysing interactions among Sustainable Development Goals with Integrated Assessment Models. *Global Transitions*, *1*, 210–225. https://doi.org/10.1016/j.glt.2019.10.004

Van Vuuren, D. P., Bijl, D. L., Bogaart, P., Stehfest, E., Biemans, H., Dekker, S. C., Doelman, J. C., Gernaat, D. E. H. J., & Harmsen, M. (2019). Integrated scenarios to support analysis of the food–energy–water nexus. *Nature Sustainability*, *2*(12), Article 12. https://doi.org/10.1038/s41893-019-0418-8

Vargo, J., Stone, B., Habeeb, D., Liu, P., & Russell, A. (2016). The social and spatial distribution of temperature-related health impacts from urban heat island reduction policies. *Environmental Science & Policy*, *66*, 366–374. https://doi.org/10.1016/j.envsci.2016.08.012

Veerkamp, C. J., Dunford, R. W., Harrison, P. A., Mandryk, M., Priess, J. A., Schipper, A. M., Stehfest, E., & Alkemade, R. (2020). Future projections of biodiversity and ecosystem services in Europe with two integrated assessment models. *Regional Environmental Change*, *20*(3), 103. https://doi.org/10.1007/s10113-020-01685-8

Veldman, J. W., Aleman, J. C., Alvarado, S. T., Anderson, T. M., Archibald, S., Bond, W. J., Boutton, T. W., Buchmann, N., Buisson, E., Canadell, J. G., Dechoum, M. de S., Diaz-Toribio, M. H., Durigan, G., Ewel, J. J., Fernandes, G. W., Fidelis, A., Fleischman, F., Good, S. P., Griffith, D. M., … Zaloumis, N. P. (2019). Comment on "The global tree restoration potential". *Science*, *366*(6463), eaay7976. https://doi.org/10.1126/science.aay7976

Verdonck, M.-L., Demuzere, M., Hooyberghs, H., Priem, F., & Van Coillie, F. (2019). Heat risk assessment for the Brussels capital region under different urban planning and greenhouse gas emission scenarios. *Journal of Environmental Management*, *249*, 109210. https://doi.org/10.1016/j.jenvman.2019.06.111

Verhagen, J. H., Fouchier, R. A. M., & Lewis, N. (2021). Highly Pathogenic Avian Influenza Viruses at the Wild–Domestic Bird Interface in Europe: Future Directions for Research and Surveillance. *Viruses*, *13*(2), 212. https://doi.org/10.3390/v13020212

Vermeulen, L. C., De Kraker, J., Hofstra, N., Kroeze, C., & Medema, G. (2015). Modelling the impact of sanitation, population growth and urbanization on human emissions of *Cryptosporidium* to surface waters—A case study for Bangladesh and India. *Environmental Research Letters*, *10*(9), 094017. https://doi.org/10.1088/1748-9326/10/9/094017

Verniest, F., Galewski, T., Julliard, R., Guelmami, A., & Le Viol, I. (2022). Coupling future climate and land-use projections reveals where to strengthen the protection of Mediterranean Key Biodiversity Areas. *Conservation Science and Practice*, *4*(11). https://doi.org/10.1111/csp2.12807

Vezzulli, L., Grande, C., Reid, P. C., Hélaouët, P., Edwards, M., Höfle, M. G., Brettar, I., Colwell, R. R., & Pruzzo, C. (2016). Climate influence on Vibrio and associated human diseases during the past half-century in the coastal North Atlantic. *Proceedings of the National Academy of Sciences*, *113*(34), E5062–E5071.

Vilas, D., Coll, M., Pedersen, T., Corrales, X., Filbee-Dexter, K., & Wernberg, T. (2021). Future trajectories of change for an Arctic deep-sea ecosystem connected to coastal kelp forests. *Restoration Ecology*, *29*(S2), e13327. https://doi.org/10.1111/rec.13327

Villarreal-Rosas, J., Rhodes, J. R., Sonter, L. J., Possingham, H. P., & Vogl, A. L. (2023). Optimal allocation of nature-based solutions to achieve climate mitigation and adaptation goals. *People and Nature*, *5*(3), 1034–1045. https://doi.org/10.1002/pan3.10481

Visconti, P., Bakkenes, M., Baisero, D., Brooks, T., Butchart, S. H. M., Joppa, L., Alkemade, R., Di Marco, M., Santini, L., Hoffmann, M., Maiorano, L., Pressey, R. L., Arponen, A., Boitani, L., Reside, A. E., van Vuuren, D. P., & Rondinini, C. (2016). Projecting Global Biodiversity Indicators under Future Development Scenarios: Projecting biodiversity indicators. *Conservation Letters*, *9*(1), 5–13. https://doi.org/10.1111/conl.12159

Visconti, P., Butchart, S. H. M., Brooks, T. M., Langhammer, P. F., Marnewick, D., Vergara, S., Yanosky, A., & Watson, J. E. M. (2019). Protected area targets post-2020. *Science*, *364*(6437), 239–241. https://doi.org/10.1126/science.aav6886

von Braun, J., Afsana, K., Fresco, L. O., & Hassan, M. (2021). *Food systems: Seven priorities to end hunger and protect the planet*. https://doi.org/10.1038/d41586-021-02331-x

Voskamp, I. M., & Van De Ven, F. H. M. (2015). Planning support system for climate adaptation: Composing effective sets of blue-green measures to reduce urban vulnerability to extreme weather events. *Building and Environment*, *83*, 159–167. https://doi.org/10.1016/j.buildenv.2014.07.018

Wade, A. J., Skeffington, R. A., Couture, R.-M., Erlandsson Lampa, M., Groot, S., Halliday, S. J., Harezlak, V., Hejzlar, J., Jackson-Blake, L. A., Lepistö, A., Papastergiadou, E., Riera, J. L., Rankinen, K., Shahgedanova, M., Trolle, D., Whitehead, P. G., Psaltopoulos, D., & Skuras, D. (2022). Land Use Change to Reduce Freshwater Nitrogen and Phosphorus will Be Effective Even with Projected Climate Change. *Water*, *14*(5), 829. https://doi.org/10.3390/w14050829

Wade, T. J., Lin, C. J., Jagai, J. S., & Hilborn, E. D. (2014). Flooding and Emergency Room Visits for Gastrointestinal Illness in Massachusetts: A Case-Crossover Study. *PLoS ONE*, *9*(10), e110474. https://doi.org/10.1371/journal.pone.0110474

Waltham, N. J., Elliott, M., Lee, S. Y., Lovelock, C., Duarte, C. M., Buelow, C., Simenstad, C., Nagelkerken, I., Claassens, L., Wen, C. K.-C., Barletta, M., Connolly, R. M., Gillies, C., Mitsch, W. J., Ogburn, M. B., Purandare, J., Possingham, H., & Sheaves, M. (2020). UN Decade on Ecosystem Restoration 2021–2030—What Chance for Success in Restoring Coastal Ecosystems? *Frontiers in Marine Science*, *7*. https://doi.org/10.3389/fmars.2020.00071

Weatherdon, L. V., Magnan, A. K., Rogers, A. D., Sumaila, U. R., & Cheung, W. W. L. (2016). Observed and projected impacts of climate change on marine fisheries, aquaculture, coastal tourism, and human health: An update. *Frontiers in Marine Science*, *3*(APR). Scopus. https://doi.org/10.3389/fmars.2016.00048

Weber, E., Downward, G. S., Ebi, K. L., Lucas, P. L., & Van Vuuren, D. (2023). The use of environmental scenarios to project future health effects: A scoping review. *The Lancet Planetary Health*, *7*(7), e611–e621. https://doi.org/10.1016/S2542-5196(23)00110-9

WEF, Ellen MacArthur Foundation, & McKinsey & Company. (2016). *The New Plastics Economy—Rethinking the future of plastics*. https://www.ellenmacarthurfoundation.org/the-new-plastics-economy-rethinking-the-future-of-plastics

Werners, S. E., Wise, R. M., Butler, J. R. A., Totin, E., & Vincent, K. (2021). Adaptation pathways: A review of approaches and a learning framework. *Environmental Science & Policy*, *116*, 266–275. https://doi.org/10.1016/j.envsci.2020.11.003

Wiik, E., Jones, J. P. G., Pynegar, E., Bottazzi, P., Asquith, N., Gibbons, J., & Kontoleon, A. (2020). Mechanisms and impacts of an incentive-based conservation program with evidence from a randomized control trial. *Conservation Biology*, *34*(5), 1076–1088. https://doi.org/10.1111/cobi.13508

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L. J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J. A., De Vries, W., Majele Sibanda, L., … Murray, C. J. L.

(2019). Food in the Anthropocene: The EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet*, *393*(10170), 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4

Williams, D. R., Clark, M., Buchanan, G. M., Ficetola, G. F., Rondinini, C., & Tilman, D. (2021). Proactive conservation to prevent habitat losses to agricultural expansion. *Nature Sustainability*, *4*(4), 314–322. https://doi.org/10.1038/s41893-020-00656-5

Wilting, H. C., Schipper, A. M., Bakkenes, M., Meijer, J. R., & Huijbregts, M. A. J. (2017). Quantifying Biodiversity Losses Due to Human Consumption: A Global-Scale Footprint Analysis. *Environmental Science & Technology*, *51*(6), 3298–3306. https://doi.org/10.1021/acs.est.6b05296

Wimmer, F., Audsley, E., Malsy, M., Savin, C., Dunford, R., Harrison, P. A., Schaldach, R., & Flörke, M. (2015). Modelling the effects of cross-sectoral water allocation schemes in Europe. *Climatic Change*, *128*(3–4), 229–244. https://doi.org/10.1007/s10584-014-1161-9

Withers, P., Neal, C., Jarvie, H., & Doody, D. (2014). Agriculture and Eutrophication: Where Do We Go from Here? *Sustainability*, *6*(9), 5853–5875. https://doi.org/10.3390/su6095853

Wöhler, L., Hoekstra, A. Y., Hogeboom, R. J., Brugnach, M., & Krol, M. S. (2020). Alternative societal solutions to pharmaceuticals in the aquatic environment. *Journal of Cleaner Production*, *277*, 124350. https://doi.org/10.1016/j.jclepro.2020.124350

Wood, C. L., McInturff, A., Young, H. S., Kim, D., & Lafferty, K. D. (2017). Human infectious disease burdens decrease with urbanization but not with biodiversity. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *372*(1722), 20160122. https://doi.org/10.1098/rstb.2016.0122

World Wildlife Fund. (2023). *Arctic Ocean Network of Priority Areas for Conservation*. Arctic Ocean Network of Priority Areas for Conservation. https://www.arcticwwf.org/our-priorities/nature/arcnet/

Wu, G. C., Baker, J. S., Wade, C. M., McCord, G. C., Fargione, J. E., & Havlik, P. (2022). Contributions of healthier diets and agricultural productivity toward sustainability and climate goals in the United States. *Sustainability Science*. https://doi.org/10.1007/s11625-022-01232-w

Wu, G. C., Baker, J. S., Wade, C. M., McCord, G. C., Fargione, J. E., & Havlik, P. (2023). Contributions of healthier diets and agricultural productivity toward sustainability and climate goals in the United States. *Sustainability Science*, *18*(1), 539–556. https://doi.org/10.1007/s11625-022-01232-w

Wu, L., Elshorbagy, A., Pande, S., & Zhuo, L. (2021). Trade-offs and synergies in the water-energy-food nexus: The case of Saskatchewan, Canada. *Resources, Conservation and Recycling*, *164*, 105192. https://doi.org/10.1016/j.resconrec.2020.105192

Wu, W., Hasegawa, T., Ohashi, H., Hanasaki, N., Liu, J., Matsui, T., Fujimori, S., Masui, T., & Takahashi, K. (2019). Global advanced bioenergy potential under environmental protection policies and societal transformation measures. *GCB Bioenergy*, *11*(9), 1041–1055. https://doi.org/10.1111/gcbb.12614

WWF. (2020a). *Bending the Curve: The Restorative Power of Planet-Based Diets | Publications | WWF*. World Wildlife Fund. https://www.worldwildlife.org/publications/bending-the-curve-the-restorative-power-of-planet-based-diets

WWF. (2020b). *Living Planet Report 2020-Bending the curve of biodiversity loss*. WWF. https://www.wwf.org.uk/sites/default/files/2020-09/LPR20_Full_report.pdf

Xia, L., & Yan, X. (2023). Maximizing Earth's feeding capacity. *Nature Food*, *4*(5), Article 5. https://doi.org/10.1038/s43016-023-00736-7

Yang, J., Yang, Y. C. E., Khan, H. F., Xie, H., Ringler, C., Ogilvie, A., Seidou, O., Djibo, A. G., van Weert, F., & Tharme, R. (2018). Quantifying the Sustainability of Water Availability for the Water-Food-Energy-Ecosystem Nexus in the Niger River Basin. *Earth's Future*, *6*(9), 1292–1310. https://doi.org/10.1029/2018EF000923

Yarzábal, L. A., Salazar, L. M. B., & Batista-García, R. A. (2021). Climate change, melting cryosphere and frozen pathogens: Should we worry…? *Environmental Sustainability*, *4*(3), 489–501. https://doi.org/10.1007/s42398-021-00184-8

Yee, S. H., Paulukonis, E., Simmons, C., Russell, M., Fulford, R., Harwell, L., & Smith, L. M. (2021). Projecting effects of land use change on human well-being through changes in ecosystem services. *Ecological Modelling*, *440*, 109358. https://doi.org/10.1016/j.ecolmodel.2020.109358

Yue, T., Liu, Y., Du, Z., Wilson, J., Zhao, D., Wang, Y., Zhao, N., Shi, W., Fan, Z., Zhao, X., Zhang, Q., Huang, H., Wu, Q., Zhou, W., Jiao, Y., Xu, Z., Li, S., Yang, Y., & Fu, B. (2022). Quantum machine learning of eco-environmental surfaces. *Science Bulletin*, *67*(10), 1031–1033. https://doi.org/10.1016/j.scib.2022.02.009

Yue, T., Wu, C., Liu, Y., Du, Z., Zhao, N., Jiao, Y., Xu, Z., & Shi, W. (2023). HASM quantum machine learning. *Science China Earth Sciences*, *66*(9), 1937–1945. https://doi.org/10.1007/s11430-022-1144-7

Zaveri, E., Russ, J., & Damania, R. (2020). Rainfall anomalies are a significant driver of cropland expansion. *Proceedings of the National Academy of Sciences*, *117*(19), 10225–10233. https://doi.org/10.1073/pnas.1910719117

Zhang, S., An, K., Li, J., Weng, Y., Zhang, S., Wang, S., Cai, W., Wang, C., & Gong, P. (2021). Incorporating health co-benefits into technology pathways to achieve China's 2060 carbon neutrality goal: A modelling study. *The Lancet Planetary Health*, *5*(11), e808–e817. https://doi.org/10.1016/S2542-5196(21)00252-7

Zhao, Z.-J., Chen, X.-T., Liu, C.-Y., Yang, F., Tan, X., Zhao, Y., Huang, H., Wei, C., Shi, X.-L., Zhai, W., Guo, F., & Van Ruijven, B. J. (2020). Global climate damage in 2°C and 1.5°C scenarios based on BCC_SESM model in IAM framework. *Advances in Climate Change Research*, *11*(3), 261–272. https://doi.org/10.1016/j.accre.2020.09.008

Zhiwei Xu, Bambrick, H., Frentiu, F. D., Devine, G., Yakob, L., Williams, G., & Hu, W. (2020). Projecting the future of dengue under climate change scenarios: Progress, uncertainties and research needs. *PLOS Neglected Tropical Diseases*, *14*(3), e0008118. https://doi.org/10.1371/journal.pntd.0008118

Zurek, M., Hebinck, A., & Selomane, O. (2021). Looking across diverse food system futures: Implications for climate change and the environment. *Q Open*, *1*(1), qoaa001. https://doi.org/10.1093/qopen/qoaa001