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Third meeting (resumed)
Agenda item 4

SUBSIDIARY BODY ON SCIENTIFIC, TECHNICAL AND TECHNOLOGICAL ADVICE
Twenty-fourth meeting (resumed)
Agenda item 3

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EXPERT INPUT TO THE POST-2020 GLOBAL BIODIVERSITY FRAMEWORK: TRANSFORMATIVE ACTIONS ON ALL DRIVERS OF BIODIVERSITY LOSS ARE URGENTLY REQUIRED TO ACHIEVE THE GLOBAL GOALS BY 2050

Note by the Executive Secretary

1. The Executive Secretary circulates herewith, for the information of participants in the third meeting of the Open-ended Working Group on the Post-2020 Global Biodiversity Framework and the twenty-fourth meeting of the Subsidiary Body on Scientific, Technical and Technological Advice, an information document providing an updated synthesis and assessment of how the actions implied by the proposed targets in the first draft of the post-2020 global biodiversity framework and a comprehensive monitoring framework could contribute to achieving the biodiversity milestones and goals (Goal A) of the framework. The document has been prepared by a group of experts convened by the bioDISCOVERY program of Future Earth and the Secretariat of the Group on Earth Observations Biodiversity Observation Network (GEO BON).

2. The document is provided in the form and language in which it was received by the Secretariat.

Expert Input to the Post-2020 Global Biodiversity Framework

Transformative actions on all drivers of biodiversity loss are urgently required to achieve the global goals by 2050

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Acknowledgements

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List of Contributors

Co-Leads and Organising Committee

Paul Leadley, bioDISCOVERY Future Earth, University of Paris-Saclay, CNRS, AgroParisTech, France;
Cornelia Krug, bioDISCOVERY Future Earth, University of Zurich, Switzerland;
David Obura, bioDISCOVERY Future Earth, Coastal Oceans Research and Development (CORDIO) East Africa;
Lynne Shannon, bioDISCOVERY Future Earth, University of Cape Town, South Africa;
Andrew Gonzalez, GEO BON, McGill University, Canada;
Maria Cecilia Londoño-Murcia, GEO BON, Instituto Alexander von Humboldt, Colombia;
Adriana Radulovici, GEO BON, McGill University, Canada;
Katie Millette, GEO BON, McGill University, Canada;
Aleksandar Rankovic, Paris Institute of Political Studies, France

Authors

Emma Archer, University of Pretoria, South Africa;
Frederick Ato Armah, University of Cape Coast, Ghana;
Nic Bax, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia;
Kalpana Chaudhari, Institute for Sustainable Development and Research (ISDR), India and Shah and Anchor Kutchhi Engineering College, India;
Mark John Costello, Nord University, Norway and University of Auckland, New Zealand;
Liliana M. Davalos, Stony Brook University, United States of America;
Fabio de Oliveira Roque, Universidade de Mato Grosso do Sul, Brazil;
Fabrice DeClerck, Alliance of Bioversity and CIAT, OneCGIAR and EAT Forum, France;
Laura Dee, University of Colorado, Boulder, United States of America;
Franz Essl, University of Vienna, Austria;
Simon Ferrier, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia;
Piero Genovesi, Italian National Institute for Environmental Protection and Research (ISPRA), Italy;
Manuel R. Guariguata, Center for International Forestry Research (CIFOR), Peru;
Shizuka Hashimoto, University of Tokyo, Japan;
Chinwe Ifejika Speranza, University of Bern, Switzerland;
Forest Isbell, University of Minnesota, United States of America;
Marcel Kok, Netherlands Environmental Assessment Agency (PBL), Netherlands;
Shane Lavery, University of Auckland, New Zealand;
David Leclère, International Institute for Applied Systems Analysis (IIASA), Austria;
Rafael Loyola, Brazilian Foundation for Sustainable Development, Brazil and Universidade Federal de Goiás, Brazil;
Shuaib Lwasa, Global Centre on Adaptation, Uganda/Netherlands;
Melodie McGeoch, La Trobe University, Australia;
Akira S. Mori, Yokohama National University, Japan;
Emily Nicholson, Deakin University, Australia;
Jose Manuel Ochoa, Instituto Alexander von Humboldt, Colombia;
Kinga Öllerer, Centre for Ecological Research, Hungary and Institute of Biology Bucharest, Romanian Academy, Romania;
Stephen Polasky, University of Minnesota, United States of America;
Carlo Rondinini, University of Rome, Italy and State University of New York, United States of America;
Sibylle Schroer, Leibniz Institute of Freshwater Ecology and Inland Fisheries, Germany;

Odirilwe Selomane, Centre for Sustainability Transitions, Stellenbosch University, South Africa;
Xiaoli Shen, Institute of Botany, Chinese Academy of Sciences, China;
Bernardo Strassburg, International Institute for Sustainability, Brazil;
Rashid Sumaila, University of British Columbia, Canada;
Derek P. Tittensor, Dalhousie University, Canada and United Nations Environment Programme World Conservation Monitoring Centre (UNEP-MCMC), United Kingdom of Great Britain and Northern Ireland;
Eren Turak, New South Wales Department of Planning, Industry and Environment, Australia;
Luis Urbina, Instituto Alexander von Humboldt, Colombia;
Maria Vallejos, Instituto Nacional de Investigación Agropecuaria, Uruguay and Facultad de Agronomía, Universidad de Buenos Aires, Argentina;
Ella Vázquez-Domínguez, Universidad Nacional Autónoma de México, Mexico;
Peter Verburg, Vrije Universiteit Amsterdam, Netherlands;
Piero Visconti, International Institute for Applied Systems Analysis (IIASA), Austria;
Stephen Woodley, International Union for Conservation of Nature World Commission on Protected Areas (IUCN WCPA), Canada;
Jianchu Xu, Kunming Institute of Botany, Chinese Academy of Sciences, China

Contributors

Sean Jellesmark, University College London, United Kingdom

Reviewers

Almut Arneth, Karlsruhe Institute of Technology, Germany;
Sandra Díaz, CONICET and National University of Cordoba, Argentina;
Mike Gill, NatureServe, Canada;
Frank Muller-Karger, University of South Florida, United States of America

About this document

A group of fifty international experts was convened by the bioDISCOVERY program of Future Earth and the Secretariat of the Group on Earth Observations Biodiversity Observation Network (GEO BON) to provide an updated synthesis and assessment of how actions in the twenty-one targets of the first draft of the post-2020 global biodiversity framework (GBF) and a comprehensive monitoring framework could contribute to achieving the biodiversity milestones and goals (Goal A) of the GBF.

Part I of this document presents the Key Messages and Executive Summary as high-level summaries for quick access by readers. Part II presents the supporting evidence in five technical sections, each of which is divided into three sub-sections (high-level findings for the global biodiversity framework, a plain-language summary and statements summarising the evidence) to aid readers in accessing the detailed content. A list of abbreviations, glossary of terms, appendices and references are appended at the end.

Part I

Key Messages

The eight Key Messages of this synthesis are highlighted below and are expanded upon in the Executive Summary. Cross-references to the findings in the Executive Summary are indicated by {ES#}.

Key Message 1: High levels of ambition for halting and reversing biodiversity loss (Goal A) cannot be met without transformative change which is a "fundamental, system-wide reorganization across technological, economic and social factors, including paradigms, goals and values, needed for the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development" {ES1, ES2}.

Achieving ambitious targets for conservation and restoration efforts such as protected areas (Target 3), species management plans (Target 5) and restoration (Target 2) is projected to slow the loss of biodiversity, but only when well implemented at international, national and local scales. There is a growing body of evidence showing that halting biodiversity loss by 2030 and reversing biodiversity loss by 2050 requires transformative change, and cannot be achieved through conservation and restoration actions alone.

In the context of the GBF, transformative change implies very ambitious actions across all of the indirect drivers of biodiversity loss including increasing the sustainability of production and consumption particularly of food (Targets 9, 10, 15, 16), closing yield gaps in agriculture (Target 10), substantially reducing subsidies and other incentives harmful to biodiversity (Targets 14, 18), considerably increasing resources for implementation and capacity-building (Target 19) and improving mainstreaming, education and equity (Targets 14-21). These actions are also fundamental components for achieving the Sustainable Development Goals.

Key Message 2: Achieving ambitious objectives for ecosystems, species and genetic diversity (Goal A) depends on a comprehensive portfolio of actions to reduce all of the direct threats to biodiversity from land and sea use change, direct exploitation of organisms, climate change, pollution, invasive alien species and their interactions {ES1, ES3}.

There is no one-to-one relationship between the direct drivers of biodiversity change and the targets acting on these direct drivers (Targets 1-10), and their influence on ecosystems, species and genetic diversity (Goal A). Biodiversity loss is caused by multiple direct drivers in nearly all cases, meaning that actions on only one or a few direct drivers will be insufficient to halt continued loss. These analyses show that the targets of the GBF form an indivisible whole that must all be ambitious in order to achieve biodiversity goals and milestones.

Limiting global climate warming to 1.5°C is essential for attaining any ambitious goals for biodiversity. The challenges of dealing with increasing climate change impacts, even at low levels of global warming, are not sufficiently well reflected in the goals and targets of the GBF. Conversely, protecting and restoring biodiversity are key to achieving the climate mitigation and adaptation goals of the Paris Agreement.

Key Message 3: Global targets of the GBF provide an important template for action, but it is how these targets are implemented and how actions are coordinated across local, national and international levels that will determine success in achieving objectives for biodiversity. Regular assessments of the implementation of targets and their contributions to progress towards clearly defined goals and milestones for biodiversity are therefore vital elements of the GBF {ES4}.

Targets of the GBF are necessarily broad, global objectives for action and, therefore, do not specify the details of how actions are implemented, even though these details are critical for success. There is a good understanding of the integrated set of actions and planning needed to achieve positive outcomes for biodiversity in a wide range of contexts, so implementation of targets will greatly benefit from a sharing of this knowledge and sustained coordination of action across levels. However, the complex relationships between actions and impacts on biodiversity make it difficult to precisely predict which combinations and levels of actions will result in success at national and international levels. It is critical to regularly assess the implementation of targets and their effectiveness in achieving clear, and if possible quantitative biodiversity objectives over time where necessary, and to adjust implementation of targets when necessary.

Key Message 4: Reversing biodiversity loss will require addressing threats to biodiversity in *both* natural and managed ecosystems, as well as the interconnections between them.

“Natural” and “managed” ecosystems differ in their species and genetic composition, ecosystem functions and supply of benefits to people, hence the targets for action, reference states, monitoring requirements and relevant indicators differ between them {ES5}.

Both natural and managed ecosystems, particularly those inhabited, or managed, by indigenous peoples and local communities with a long history of integration with nature, may make large contributions to conserving biodiversity and meeting peoples' needs. The contributions of managed ecosystems, and the mosaic of natural habitats within them, need to be better reflected in the goals and targets of the GBF.

We suggest extending Milestone A.1 to include reference to managed ecosystems by appending the phrase: “... *and [net gain] in the integrity of managed ecosystems of at least XX per cent.*” In practice, actions to improve the integrity of managed ecosystems could include increasing the genetic and species diversity of managed organisms they contain, increasing the area of native habitat that they contain, or better connecting them to surrounding natural ecosystems via corridors.

Key Message 5: All dimensions of biodiversity — genetic, trait, population, species, community and ecosystem — show interlinked responses to human drivers. Efforts to mitigate the effects of drivers on one dimension (e.g., population abundances) will depend on action on other dimensions (e.g., genetic diversity). Knowledge of the interlinked relationships between dimensions of biodiversity can be used to guide prioritization for conservation {ES6}.

Different dimensions of biodiversity interact to determine the ecological outcomes that are the focus of the GBF. Action on targets can account for the fact that drivers act on multiple dimensions of biodiversity at the same time. Action to maintain genetic diversity will benefit population persistence and lower extinction rates, while action on species diversity and composition can maintain ecosystem processes and recovery.

Accounting for these interdependencies (i) brings greater clarity to the formulation of the quantitative elements of the goals, milestones and targets of the GBF, (ii) strengthens actions on drivers that promote recovery across multiple dimensions and, (iii) supports the translation of global targets to national and local action plans.

Priority regions for conservation of different dimensions may not overlap, so complementarity-based prioritization for conservation of distinct dimensions is needed. Large gaps in the coverage for each dimension of diversity can be reduced by an expansion of protected areas, but large gains in biodiversity protection are possible if different biodiversity metrics are considered together while establishing protected areas, restoration measures, and the range of actions that are necessary to address the drivers of biodiversity loss.

Key Message 6: Ambitious action is needed as soon as possible and must be sustained over time if we are to put biodiversity on a trend to recovery by mid-century. There is good evidence that while some dimensions of biodiversity recover rapidly following conservation action, many show long-lasting, or time-delayed, changes in response to actions to mitigate the effects of drivers {ES7}.

The timing of goals and milestones for biodiversity conservation and restoration must account for time lags at several levels: i) in the implementation of action, ii) the change in strength of direct drivers resulting from action on indirect drivers, and iii) the response of different dimensions of biodiversity to changes in drivers. Time-lagged responses of all dimensions of biodiversity can be measured in decades, which highlights the importance of monitoring for recovery and restoration outcomes with appropriate reference conditions and baselines.

Time delayed responses by different aspects of biodiversity change, such as extinction rates and ecosystem recovery, can be shortened if action is implemented immediately to reduce the effects of drivers. Crucially, immediate action will also lower the cumulative loss of biodiversity and shorten the time and increase the probability of recovery, and result in overall lower costs in the long-term. The time needed for safeguarding and restoring ecosystem structure, function and resilience is particularly critical for people and communities whose livelihoods and well-being directly depend on these ecosystems and the benefits they provide.

Key Message 7: The degree of biodiversity change, and relative importance of drivers, vary greatly across scales and from place to place, and drivers in one place can affect biodiversity far away in other places {ES8}.

The targets and the monitoring framework of the GBF need to be designed to i) enable a cross-scale analysis of biodiversity and driver change, ii) address accountability for actions and means of implementation of both Parties and non-state actors, and iii) support both integration and disaggregation of national responsibilities for achieving targets, including resource needs.

International collaboration should be strengthened and focused on how to share the efforts adequately and equitably i) to mitigate the drivers of biodiversity loss, ii) to protect, conserve and restore biodiversity, as appropriate, and iii) to account for differences in national capacities and access to the means of implementation. This must be complemented by localised target-setting anchored in stakeholders' realities, with a special focus on indigenous peoples and local communities, to assure local and national priorities and interests are also met, including assuring the provisioning of nature's contributions to people.

Key Message 8: Successful implementation of the GBF requires substantial investment in monitoring capacity to detect change and attribute drivers. There is a need to ensure the supply of, and access to, data that underpin the effective use of indicators to track progress and guide action needed to implement the GBF at local, national and international levels. The set of indicators for monitoring progress to Goal A of the GBF should be expanded to comprehensively cover outcomes, drivers and actions and the interdependencies between them {ES9}.

The production of indicators relies on the data that underpin them. Some dimensions of biodiversity change are covered by effective indicators, however, monitoring is needed for attribution of observed biodiversity change to drivers through coordinated investment in adaptive monitoring and data collection.

Three complementary approaches to the use of indicators are needed to realise the outcomes of the GBF: 1) to report on overall progress towards targets and goals (headline indicators focusing on biodiversity outcomes); 2) to understand how drivers cause biodiversity change, thereby allowing changes in biodiversity to be attributed to changes in drivers and actions (component and complementary indicators that include indicators for drivers and actions); and 3) to inform strategic planning of actions to effectively and efficiently achieve targets and goals, through the use of indicators to inform strategic planning of actions to effectively and efficiently achieve targets and goals. Enhancing local and national capacities, with a special focus on the traditional and local knowledge held by indigenous peoples and local communities, to generate and deliver biodiversity information will increase the capacity of different stakeholders to produce and use biodiversity indicators in strategic planning and assessment processes.

Executive Summary

Introduction

The IPBES Global Assessment (2019) has clearly shown that transformative change is needed to conserve biodiversity, restore degraded ecosystems and build back the capacity of ecosystems so as to support life and nature's contributions to people. Reducing and ultimately eliminating the negative effects of direct drivers of biodiversity change – land and sea use change, direct exploitation, climate change, pollution and invasive alien species – is crucial to achieving the post-2020 global biodiversity framework (GBF)[1] goals.

To achieve a transformative change we must also address the indirect social and economic drivers of biodiversity loss. High ambition to halt the loss of biodiversity and of nature's contributions to people in the goals and milestones of the GBF requires ambitious, systemic and sustained efforts to address the full range of direct and indirect drivers of biodiversity change. The twenty-one targets for 2030 point to different actions that are necessary to achieve outcomes reflected in the 2050 goals and associated 2030 milestones (Figure 1).

Parties to the Convention on Biological Diversity (CBD) and many stakeholders have noted that the links between the action targets and the outcomes in terms of biodiversity (Goal A) need to be made clearer. Scientific input on these links can clarify how and where we must invest in the 2030 action targets to achieve the 2050 goals.

A group of international experts was convened by the bioDISCOVERY program of Future Earth and the Secretariat of the Group on Earth Observations Biodiversity Observation Network (GEO BON) to provide an updated synthesis and assessment of how changes in the magnitude of the drivers responsible for biodiversity change (i.e., how the action targets are implemented) could lead to success or failure as measured by achieving biodiversity milestones and goals of the GBF.

[1] This document cites the first draft of the post-2020 global biodiversity framework, CBD/WG2020/3/3, dated 5 July 2021.

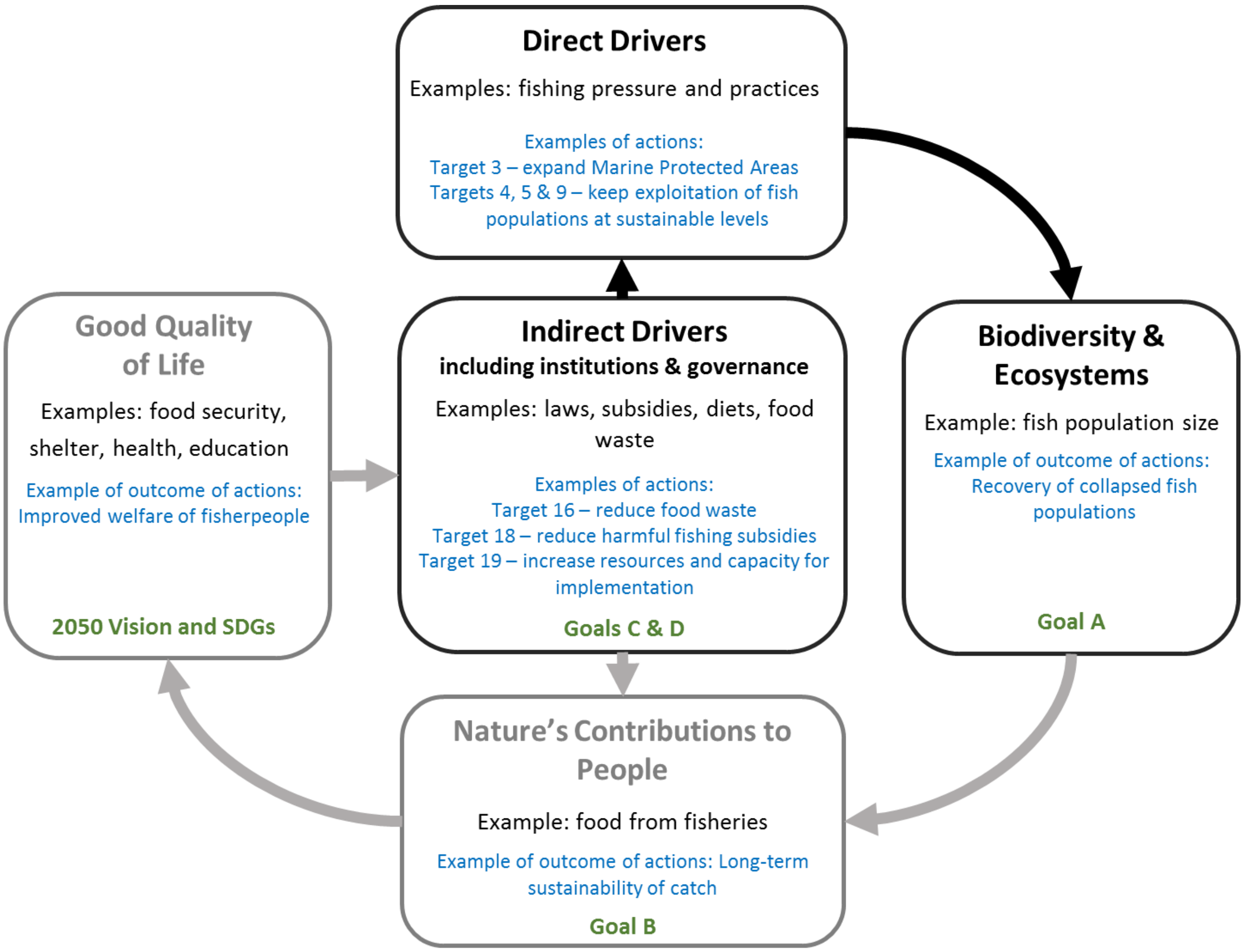


Figure 1. ***A simplified version of the IPBES conceptual framework illustrating key terms used in this document.*** *Main elements of the IPBES Conceptual Framework (CF; Díaz* et al. *2015) are indicated in large bold titles with examples provided immediately below. Green text indicates the four goals of the global biodiversity framework (GBF). Blue text provides a non-exhaustive example of how actions embodied in the targets of the GBF could lead to recovery of overexploited marine fish populations and the contributions this makes to people. Direct drivers are factors that directly impact biodiversity and are generally grouped into five main categories — land and sea use change, direct exploitation, climate change, pollution and invasive alien species. Indirect drivers are socio-economic factors, such as human population growth, consumption patterns and institutions that underlie changes in direct drivers. Biodiversity & Ecosystems includes ecosystem, species and genetic dimensions of Nature (*sensu *Díaz* et al. *2015). The objectives for biodiversity in 2050 are set out in Goal A of the GBF. Milestones are intermediate objectives for 2030 (not shown). Actions that modify indirect and direct drivers are set out in the 21 Targets of the GBF. This document focuses on the elements indicated above (in black boxes, text and arrows), but also includes some discussion of other elements of the IPBES CF (in grey outline, text and arrows) as well as Goals B (Nature's contributions to people), C (Benefit sharing) and D (Means of implementation) of the GBF. Note*

that the widely used terminology from the Driver-Pressure-State-Impact-Response (DPSIR) framework differs from the IPBES CF and the correspondence is as follows (IPBES CF → DPSIR): Indirect Drivers → Drivers; Direct Drivers → Pressures; Biodiversity & Ecosystems → State & Impacts; Actions → Response.

In this context, this synthesis has three primary objectives:

- to show how the Action Targets are related to the outcomes for biodiversity set out in the goals and milestones of the GBF;
- to generate an evidence-based reflection on how to set the ambition needed to immediately address the drivers of biodiversity loss in order to maximise chances to stay on track to meet the 2030 milestones and 2050 goals;
- to demonstrate the importance of employing indicators that account for progress towards goals and targets, inform strategic planning of actions needed to achieve the GBF outcomes, and enable attribution of observed biodiversity change to drivers (direct and indirect) through well-coordinated investment in monitoring and ongoing data collection.

With these objectives in mind, we identify factors that may prevent or slow progress, and we identify which actions are likely to be most effective in overcoming them. We have focused on Goal A (ecosystems, species and genetic diversity) and associated milestones because of the short time frame to prepare this report and the scope of the expertise brought together. Many of the analyses are also highly pertinent to the other goals of the GBF because of their direct relationships to Goal A and to achievement of the targets.

Main Findings

We have distilled the information provided by the expert group into a set of nine main findings. The detailed information backing these findings is available in the five Technical Sections (cross-references to the sections are indicated by {S#}) that constitute the rest of the document. This summary focuses first on the relationships between targets, milestones and goals in the GBF, then on indirect drivers to emphasise the urgent need for transformative change, followed by an overview of the relationship between direct drivers and their impacts on the different dimensions of biodiversity. The remaining findings address important issues related to implementation and review, relationships between different dimensions of biodiversity, the treatment of natural and managed ecosystems, temporal lags, international collaboration and monitoring.

1 There is no one-to-one linkage from any action target to a given milestone or goal; instead, "many-to-many" relationships exist among them. Actors must thus address these complex relationships among targets, milestones and goals when planning and implementing them in an integrated manner {S1}.

Achieving the global biodiversity framework will depend on effectively linking actions on its targets, milestones and goals. Given the need for brevity, the text of the GBF is not explicit about i) how the targets and means of implementation collectively add up to achieve the goals and their associated milestones, and ii) the interdependence between these elements, so we elucidate these here (Figure 2).

The outcomes for biodiversity (in Goal A and Milestones A1-3) are delivered by actions that address both direct and indirect drivers of biodiversity loss. Most of the action targets correspond roughly to direct and indirect drivers classified by IPBES (2019). Targets 1 to 8 correspond to the five direct drivers of biodiversity loss: land and sea use change (T1/2/3), direct exploitation of species (T5), invasive alien species (T6), pollution (T7) and climate change (T8). Targets 9-13 correspond to the use of biodiversity and provisioning of benefits to people. Targets 14-21 correspond to a mix of IPBES's four broad classes of indirect drivers (demographic and sociocultural, economic and technological, institutions and governance, conflicts and epidemics); as well as tools and solutions for implementation of the framework. These are not simple relationships. For example, Target 1 addresses both the protection of intact and wilderness areas and provides the spatial planning framework for implementation and integration of all action targets together; Target 3 is focused on spatial protection, but it also directly influences exploitation and drivers such as pollution and alien species; Target 4 broadly addresses direct drivers of species decline as well as *ex-situ* actions.

No goal or milestone can be achieved from a focus on just one target, and any one target impacts on multiple milestones (Figure 2, see also Finding 3 below). Importantly, due to interdependencies among actions, the sequencing of actions and results and time lags {S2}, resources to support actions that reduce indirect and direct drivers must be significantly expanded first (1-3 years) to enable achievement of biodiversity outcomes in the medium (5-10 years) and longer (10-30 years) terms.

This integration among targets, milestones and goals reflects the same principle of indivisibility embodied in the Sustainable Development Goals (SDG), and requires actions to be integrated across the whole of government and society.

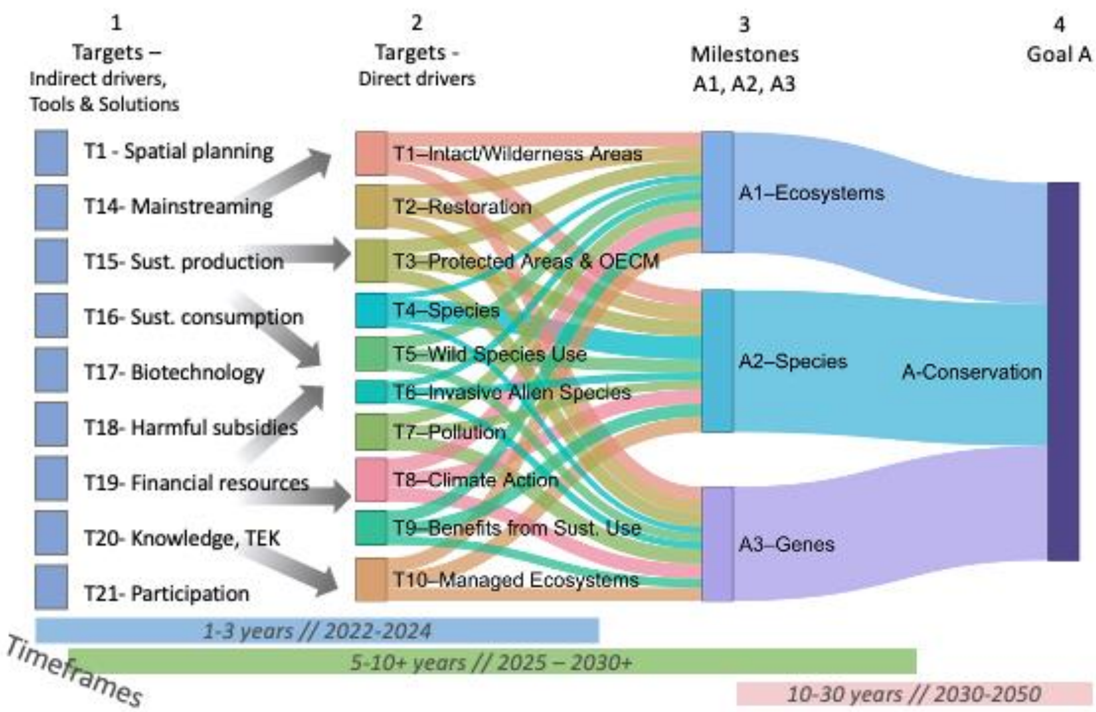


Figure 2. *There is no one-to-one linkage from any action target (T1-T21) to a given milestone (A1-3) or goal (A); actors must address the complex relationships among targets and milestones when planning, and implement them in an integrated manner. This illustration focuses on Goal A and the influence of action targets T1-T10 on milestones A1, A2 and A3 quantified based on the IPBES Global Assessment*

(see Figure 3, and Appendix 1.1), and building on the GBF Theory of Change (as expressed in the Co-Chairs reflections[2], Figure 1). The timeframe illustrates the sequencing needed between provisioning of means of implementation and action on indirect drivers, on direct drivers and then biodiversity outcomes. The figure does not address more complete interactions involving Targets 11-13 and Goals B, C and D, to make reading of this figure easier. Abbreviations: 'Sust' - Sustainable; 'OECM' - Other Effective Conservation Measures.

2 High levels of ambition for conservation and restoration of biodiversity (Goal A) cannot be met without transformative change[3]. Transformative change implies high ambition for actions on indirect drivers embodied in Targets 14-21 ("Tools and solutions for implementation and mainstreaming") as well as Targets 1 (spatial planning), 9 (sustainable fisheries) and 10 (sustainable agriculture, aquaculture and forestry) {S1}.

The IPBES Global Assessment and the Global Biodiversity Outlook 5 (GBO 5) documented little, or no, progress on most aspects of indirect drivers associated with transformative change over the last decade despite ambitious objectives set out in the Aichi Targets and other multilateral environmental agreements. Three broad types of scenarios relevant to the GBF can be distilled from analyses of recent trends and future projections (Table 1). They differ in the ambition and achievement of the targets acting on indirect drivers. All three types of scenarios assume that global warming is held to 1.5°C. Lack of progress on limiting global warming to 1.5°C is likely to seriously compromise attaining ambitious goals for biodiversity, especially ecosystem integrity, species abundance and distribution and species extinction risk. In a complementary fashion, ambitious action on biodiversity is necessary to achieve climate mitigation and adaptation goals set out in the Paris Agreement and recently reaffirmed at UNFCCC COP26 (Decisions 1/CP.26 and 1/CMA.3).

- **Continued Trends** - This type of scenario assumes that, based on past trends, very good progress is made on a few elements of targets, in particular very ambitious increases in protected area coverage. The continuation of current trends for other drivers leads to the assumptions of little, or at best modest progress on protected area efficacy, production and

[2] CBD/WG2020/3/6 (https://www.cbd.int/doc/c/2f74/dda0/270258bf5deaab47fbc43da4/wg2020-03-06-en.pdf)
[3] The IPBES Global Assessments defined transformative change as a "fundamental, system-wide reorganization across technological, economic and social factors, including paradigms, goals and values, needed for the conservation and sustainable use of biodiversity, long-term human wellbeing and sustainable development."

consumption, harmful subsidies, insufficient resources allocated to biodiversity conservation and restoration, inadequate reinforcement of rights-based approaches (for indigenous peoples and local communities (IPLCs) in particular), and other aspects of Targets 9-21. Failure to make significant headway on sustainable use and tools and solutions for implementation and mainstreaming will compromise progress towards most of the targets aimed at reducing threats to biodiversity. As a result, little progress is projected to be made towards achieving ambitious goals and milestones for biodiversity (Goal A).

- **Conservation and Restoration** - This type of scenario assumes high ambition for and achievement of targets focusing on area-based conservation, restoration and species management (Targets 1-4). It also assumes that implementation of these conservation and restoration actions is greatly improved compared to current trends through enhanced resources, education, governance and engagement of IPLCs. However, it also assumes that little progress is made on key indirect drivers such as sustainable production and consumption or harmful subsidies. Biodiversity loss is slowed compared to the Continued Trends scenario, but is not halted or reversed. Greater progress cannot be expected due to increasing impacts of land and sea use change and direct exploitation outside of protected areas, and increasing impacts of climate change, pollution and invasive alien species (IAS) everywhere. The positive effects of conservation and restoration actions are jeopardised by the continuous increase in negative impacts by these drivers, leading to inefficiency of actions and displacement of negative impacts.
- **Transformative Change** - This type of scenario assumes high ambition and achievement of the complete set of targets in the GBF. This is projected to lead to halting several components of biodiversity loss by 2030 and significant recovery by 2050. As noted in the IPBES Global Assessment and GBO 5, pathways to reduce, halt and reverse biodiversity loss require a portfolio of measures, including sustainable production and consumption alongside conservation and restoration of biodiversity. The benefits of closing yield gaps in agriculture, reducing food waste and converging on sustainable diets are particularly large and well-studied. However, even with high ambition for transformative change, the goals and milestones for biodiversity conservation and restoration should take into account time lags following implementation, the lags in the response of direct drivers to indirect drivers and the lags in the response of different dimensions of biodiversity to changes in drivers {ES7}. In particular, goals for 2050 can be more ambitious than the milestones for 2030, but only if ambitious action is taken now.

Table 1. ***Three types of scenarios for 2030 with different levels of ambition for the supporting processes and means of implementation in the GBF*** *(Targets 14-21, plus parts of 1, 9 and 10). The "Continued Trends" scenario is based on observed progress on direct and indirect drivers of biodiversity loss over the recent past. The "Conservation and Restoration" scenario is based on ambitious actions that focus on traditional conservation actions and restoration, but assumes continued trends for other major indirect drivers such as unsustainable production and consumption, subsidies that are harmful for biodiversity and mainstreaming. The "Transformative Change" scenario assumes high ambition and achievement of all of the supporting processes and means of implementation in the GBF. These scenarios are based on a synthesis of recent projections from scenarios and models, case studies and recent trends {S1, and quantitative analysis in Appendix 1.3}. Levels of progress indicated in the table correspond to achievement of targets in the GBF at their current level of ambition: no progress = no improvement over current state; little progress = very weak progress toward target and largely insufficient; modest progress = progress towards target, but relatively far from full achievement; good progress = substantial progress towards target, but target not fully achieved; very good progress = target achieved or nearly achieved.*

	Scenario Type		
	Continued Trends	**Conservation & Restoration**	**Transformative Change**
Summary of assumptions for scenario types			
Protected areas	• 30% area - very good progress • Efficacy and representativity - little, or at best modest progress	• 30% area - very good progress • Efficacy and representativity - very good progress	• 30% area - very good progress • Efficacy and representativity - very good progress
Restoration, spatial planning & species management	• Modest progress on restoration on land • Little progress on other aspects	• Very good progress on all targets	• Very good progress all targets
Sustainable use, pollution, IAS and Targets 9-21	• Little, or at best modest progress on most targets	• Little, or at best modest progress on most targets	• Very good progress all targets
Details of assumptions and of projected outcomes for biodiversity milestones			
(1) Assumptions concerning ambition and achievement of supporting	• Low ambition or little progress to 2030 for supporting processes and means of implementation. This assumes that these continue to follow observed trends	• High ambition and good progress on resources, capacity and implementation for spatial planning, restoration, protected areas, and species management	• High ambition and very good progress on all elements of supporting processes and means of implementation of the GBF. • For example, very good

processes and means of implementation (primarily Targets 14-21, plus parts of 1, 9 & 10)	from 2010-2020. ● For example, current trends are: no progress on subsidies harmful to biodiversity (T18); and modest, but insufficient progress on mainstreaming, accountability, inclusiveness and monitoring (T14-15, 20-21), as well as sustainability of production and consumption (T9, 10, 16; IPBES 2019, GBO 5 2020). ● Increasing, but insufficient resources for ambitious implementation (T19).	plans (T1 and T19, but only focused on conservation and restoration measures). ● Modest progress on mainstreaming of biodiversity values and accountability, education and inclusiveness, and monitoring. ● Low ambition or weak progress on sustainable production and consumption and managed ecosystems, harmful subsidies, and resources to support transformative change (T19).	progress in spatial planning, reducing harmful subsidies, food waste; convergence on sustainable diets; in making agriculture, forestry, aquaculture and fisheries sustainable; integration of biodiversity in national development plans; and effective participation in decision-making by IPLCs. ● Full operative use of the monitoring framework through investment in a global biodiversity monitoring system.
(2) Projected progress on reducing threats to biodiversity, based on assumptions in (1) (Targets 2-8 and parts of 1, 9 & 10)	● Good progress (potentially) on ambitious protected area % coverage target (T3). ● Modest progress on ambitious targets for restoration on land, less so for marine (T2). ● Little progress on targets for protected area efficacy and representativity (T3), sustainable use (T5, T9, T10), invasive alien species (T6), pollution (T7) and climate adaptation in natural systems (T8) and nature-based solutions for climate change (T8).	● Good progress on area-based conservation, species-based management plans especially for high priority species (T4), ecosystem restoration, nature-based contributions to climate change, and climate adaptation in natural systems (T8) ● Modest progress on sustainable use. ● Little progress on invasive alien species, pollution.	● Good or very good progress for actions on all direct drivers (T1-T7). ● Very good progress on nature-based contributions to climate change and climate change adaptation (T8), as well as integrating conservation in managed ecosystems (T9, 10).
(3) Outcomes for biodiversity by 2030 (Milestones A.1, A.2, A.3) based on assumptions in (1) and projected progress on threats (2)	● Little progress and high heterogeneity for most dimensions of biodiversity. ● Potentially large increase in area of protected areas is largely ineffective in halting decline of biodiversity due to relatively low efficacy and representativity. ● Low integration of nature in managed land- and sea-scapes. ● Rising impacts of all five direct drivers inside and outside of protected areas.	● Good progress for reducing the extinction rate of birds, mammals and some other charismatic species groups, and for net change in ecosystem area. ● Modest and heterogeneous progress for ecosystem integrity, species extinctions of invertebrates, species abundance, genetic diversity; improved connectivity across managed ecosystems. ● Rising impacts of all direct drivers inside and outside of protected areas compromise meeting ambitious goals.	● Very good progress for reducing the extinction rate of birds, mammals and other charismatic species groups, and for net change in ecosystem area. ● Good progress for ecosystem integrity and connectivity across natural and managed ecosystems. ● Good progress for species extinctions in invertebrates, genetic diversity.

3 **All five of the principal direct drivers of biodiversity loss — land and sea use change, direct exploitation, climate change, pollution, invasive alien species and their interactions — have substantial impacts on all dimensions of biodiversity. This means that high ambition for biodiversity goals and milestones can only be achieved with high ambition and achievement of all the actions to reduce threats to biodiversity {S1}.**

Figure 2 builds on evidence from IPBES assessments and shows that each of the dimensions of biodiversity in Goal A depends on all of the action targets on drivers to reduce threats to biodiversity (Targets 1-10). This many-to-many relationship means that actions can benefit all dimensions of biodiversity. It also means that any single action is only part of a more extensive portfolio of coherent actions necessary to conserve and restore biodiversity. Finally, focusing on only a subset of actions will result in only partial achievement of the biodiversity and societal outcomes of the GBF, and sub-optimal use of resources invested.

For many well-studied ecosystems and species, we know the relative importance of the direct drivers of biodiversity loss (Figure 3), as well as the actions that have been successful in slowing or reversing this loss (Figure 4).

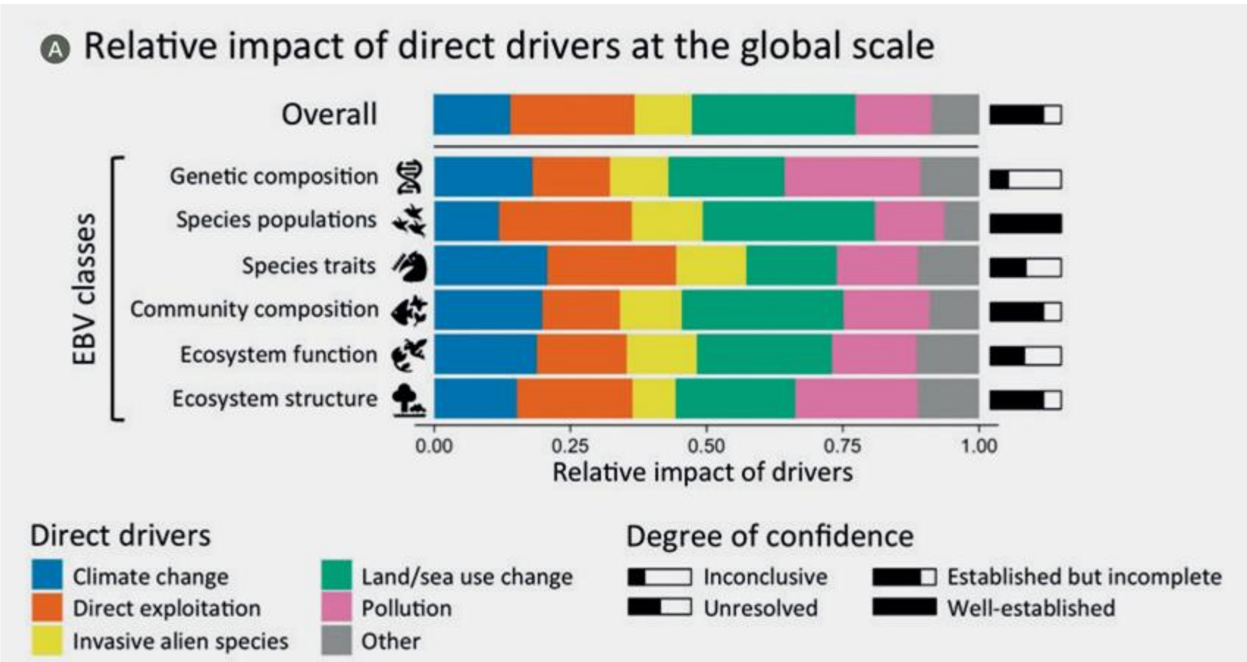


Figure 3. ***Relative importance of direct drivers across dimensions of biodiversity*** *(from IPBES 2019, Figure 2.2.22A). Confidence levels in attribution are indicated by the black bars. See other figures*

summarising across regions, realms and indicators in Section 2.2.5 of the IPBES Global Assessment.

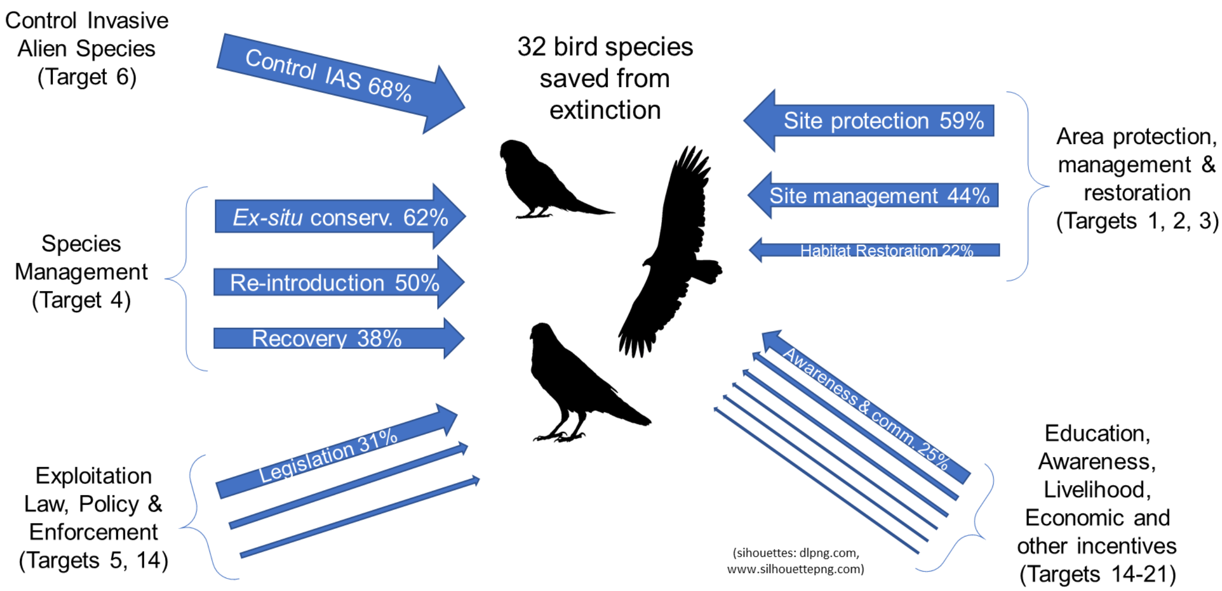


Figure 4. ***Multiple actions in combination were required to save 32 species of birds from extinction over the period 1993-2020.*** *Each arrow indicates a type of action taken to prevent extinction of birds based on the IUCN action classification scheme level 2. Conservation actions are indicated for 32 bird species for which extinction was judged to have been likely to have occurred in the absence of action during the period 1993–2020. Percentages and widths of arrows indicate the proportion of bird species for which conservation actions were taken. The total of percentages is 440% because most species required multiple actions. Text for actions that involved less than 20% of species are not provided, but can be found in the Section 1 of the Technical Synthesis (Figure 1.8). Redrawn from Bolam* et al. *(2021).*

Three examples illustrate this understanding and its implications for the GBF. First, recent bird extinctions have primarily been driven by invasive alien species, disease, hunting, habitat loss and habitat degradation, so the most critical actions for avoiding extinctions have been concerted actions including control of invasive alien species; habitat protection, management and restoration; bans on hunting; and intensive *in-situ* and *ex-situ* conservation plans (Figure 4). Second, mammal extinctions have primarily been driven by hunting and collecting, habitat loss and habitat degradation, so the most important actions for avoiding extinctions have been concerted actions to reduce or halt exploitation; habitat protection, management and restoration; and intensive *in-situ* and *ex-situ* conservation plans. Third, at the ecosystem level, tropical coral reefs are being degraded worldwide by global warming in combination in many places with overfishing, pollution and invasive alien species. Successful conservation and restoration of reefs and increasing their resilience to climate change often requires multiple actions to protect sites from exploitation, reduce pollution from boats and agricultural run-off, and control invasive alien species. However, even these concerted actions are often insufficient to fully protect coral reefs from climate change, so active restoration is used to aid in recovery for severe bleaching events and increase long-term resilience. These three examples illustrate that the relative importance and specific nature of actions are highly context-dependent, which requires taking multiple actions on multiple drivers simultaneously to address the different dimensions of biodiversity loss (illustrated here by examples of different taxa and ecosystems). Despite this high context dependence, several broad classes of these actions are common to other systems.

4 How targets of the GBF are implemented at international, national and local levels will be a primary determinant of success in achieving positive outcomes for biodiversity embodied in Goal A. The effectiveness of the implementation targets at these various levels should be measured by the contribution to clear, and where possible quantitative, objectives for biodiversity {S1, S3, S4}.

The global scale targets of the GBF are necessarily broad and therefore leave considerable leeway in implementation. For example, Target 3 the GBF does not prescribe how the global numerical target for the percent area of protected areas should be translated into national commitments, precisely where protected areas should be located, or what levels of human activities should be allowed. Yet it is well documented that these details of implementation are keys to successful conservation of biodiversity by protected areas {S1, S3}. It is important that Parties have the flexibility to adapt the implementation of targets to local and national contexts using the best available knowledge, but there is also a need to determine if the implementation of targets is achieving what they were intended to do.

Effective implementation of targets will depend on i) setting clear, and where possible quantitative objectives for outcomes for biodiversity at several points of time in the future, ii) planning and implementation of actions oriented towards these outcomes from the outset, iii) regular evaluation of the implementation of targets and their contribution to achieving these outcomes and iv) adjustment of implementation of targets when and where necessary {S4}. This has three implications for further development of the GBF. First, it is important to maintain clear, and where possible quantitative goals for 2050 and milestones for 2030, because these provide a guiding light for determining whether the implementation of the targets are achieving the intended outcomes. Second, greater emphasis on indicators quantifying the links between drivers and biodiversity change would help to monitor and predict the success of actions and to revise them proactively. Third, it is recognised in the GBF that the possibility to adjust ambition or implementation of targets would be desirable, but it would be important to have a clearer mechanism for doing so (see also CBD/SBI/3/INF/11).

5 Reversing biodiversity loss will require addressing threats to biodiversity in *both* natural and managed ecosystems, as well as the interconnections between them. Natural and managed ecosystems differ in their species and genetic composition, ecosystem functions and their support for human needs, hence the targets for action, reference states, monitoring requirements and relevant indicators may differ between them {S5}.

One quarter to one half of ice-free land is considered natural, depending on the definition of "natural ecosystems". Large wild areas constitute roughly one quarter and semi-natural ecosystems cover about one fifth of land area. In the ocean, roughly one third is considered to be natural, with low to minimal signal of human impact. Both natural and managed ecosystems may make large contributions to conserving biodiversity and meeting peoples' needs.

"Managed ecosystems" are those whose biotic composition and functioning is more heavily transformed by deliberate manipulation, often to meet specific human needs, such as food production, shelter or recreation (see Glossary on 'managed' and 'natural' ecosystems). Managed ecosystems may include built-up areas, cropland, some rangelands, tree plantations, aquaculture and reservoirs. The term "converted ecosystems" is sometimes used, and may refer to natural ecosystems that have been converted to managed ecosystems. Conversion often leads to large changes in species composition, ecosystem function and ecosystem services, but converted ecosystems are not necessarily considered as degraded if their functionality remains high, at least in some aspects.

"Natural" and "managed" ecosystems coexist in the complex mosaics (see Figure 5) where people live close to, and interact with, biodiversity and where ecological functions may be transformed towards optimizing the provisioning of certain benefits to people. The mix of ecosystem states across such mosaics can vary greatly. Retaining and restoring natural ecosystems is a top priority for "bending the curve" for biodiversity because of the role that ecosystems have in hosting all dimensions of biodiversity, and in supplying many essential contributions to people.

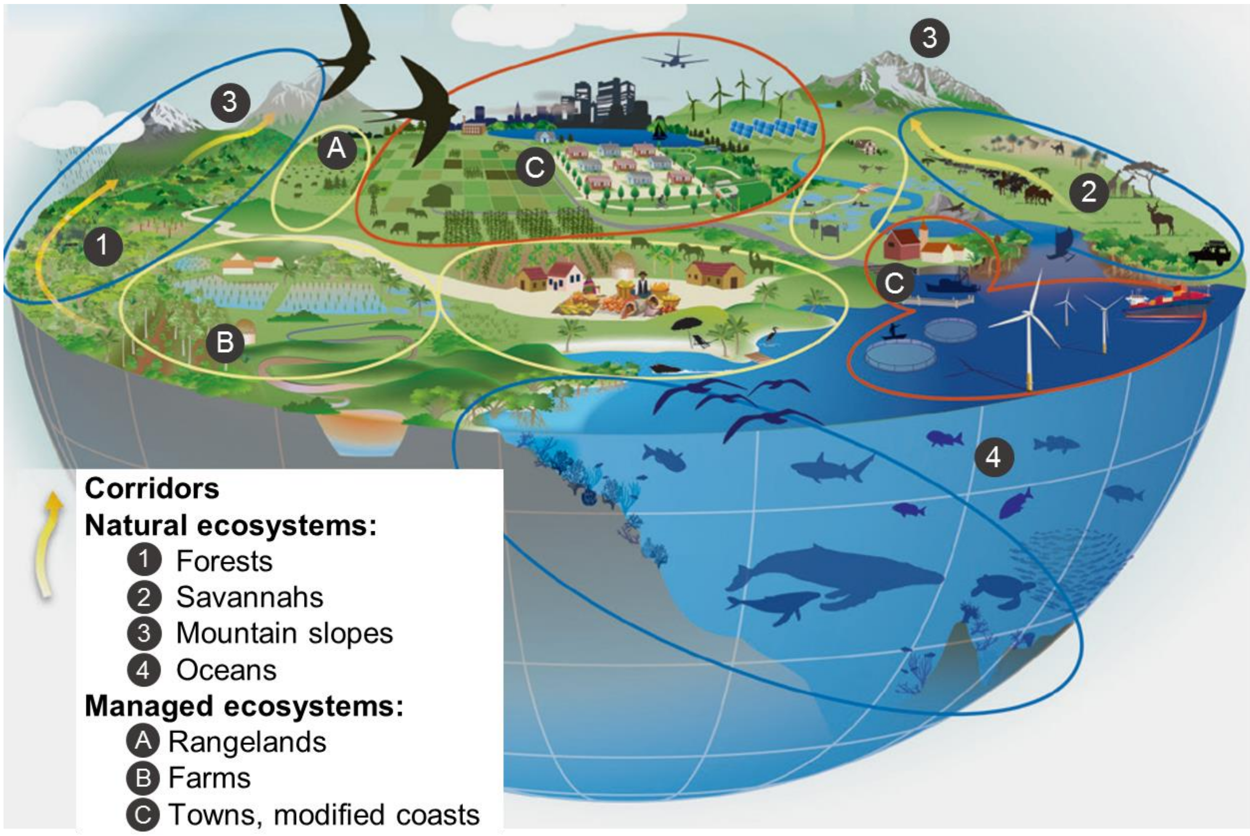


Figure 5. ***The mosaic of natural and managed ecosystems across a 'multifunctional scape'*** *can integrate large, intact wilderness areas (blue circles), a mosaic of natural ecosystems and managed ecosystems in 'shared spaces' where human population density is low to moderate (yellow circles) and fully transformed managed ecosystems in cities, intensive agriculture and highly modified coastal zones (red circles;* Source*: Pörtner* et al. *2021, modified to indicate "Managed ecosystems").*

Managed ecosystems also play a critical role in biodiversity conservation, and their functioning depends strongly on biodiversity. Many managed ecosystems have a very long history of extensive management and integration of indigenous peoples and local communities with nature, such as Cultural Landscapes recognised by the World Heritage Convention (WHC), Globally Important Agricultural Heritage Systems (GIAHS) designated by the Food and Agriculture Organization of the United Nations (FAO) and other socio-ecological production landscape and seascape initiatives (e.g., Satoyama Initiative) designed around living in harmony with nature. Such managed ecosystems may have high habitat and species conservation priorities in their own right. Further, managed ecosystems may provide habitat for many species that can make use of both natural and managed ecosystems (such as insect pollinators), and importantly, managed ecosystems may provide connectivity between natural ecosystems; these features contribute to the ecological integrity of both natural and managed ecosystems. Moreover, human well-being is dependent on the ecological functioning of managed ecosystems. Loss of biodiversity in agricultural systems leads to reduced pollination and increased pest pressure, lowering yields and increasing dependence on often harmful inputs. Loss of biodiversity in densely populated environments has been proven to have adverse impacts on both physical and mental health.

The contributions of natural ecosystems to Goal A are reflected in Milestone A1, citing area, connectivity and integrity (see Glossary for terms) as critical elements of ecosystems. However, to better incorporate the contributions of managed ecosystems, extending Milestone A.1 with the additional phrase "... *and [net gain] in the integrity of managed ecosystems of at least 20 per cent*" is suggested (see {S3} for additional options; Díaz *et al.* 2020; Garibaldi *et al.* 2021 for the percentage amount). In practice, gains in managed ecosystems integrity could mean, e.g., increasing the genetic and species diversity of managed organisms they contain, increasing the amount of native habitats (and thus species) that they contain, or better connecting them to surrounding natural ecosystems. In order to avoid diluting the gains in area, connectivity and integrity of natural ecosystems which are necessary for the achievement of multiple outcomes of the GBF, it is critical that the goals and milestones for natural ecosystems are kept distinct from (and not fungible with) the proposed gains for managed ecosystems.

6 All dimensions of biodiversity — genetic, trait, species, population, community and ecosystem — show interlinked responses to human drivers. Efforts to mitigate the effects on drivers on one dimension (e.g., population abundances) will depend on action on other dimensions (e.g., genetic diversity). Knowledge of the interlinked relationships between dimensions can be used to guide prioritization for conservation {S1, S4}.

Different dimensions of biodiversity interact to determine the ecological outcomes that are the focus of the GBF. Action on targets can account for the fact that drivers act on multiple dimensions of biodiversity at the same time. Action to maintain genetic diversity, will benefit population persistence and lower extinction rates. While action on species diversity and composition can maintain ecosystem processes and recovery {S1}.

The goals and milestones of the GBF list eight outcome measures to guide action. These include a mix of biodiversity dimensions (genetic diversity, population abundance) with measures of ecosystem structure (area, connectivity), ecosystem integrity (see Glossary) and measure of rates of change (extinction rate) or expected change (extinction risk). Accounting for the interdependencies among these measures can (i) bring greater clarity to the formulation of the quantitative elements of the goals, milestones and targets of the GBF, (ii) strengthen actions on drivers that promote recovery across multiple dimensions and, (iii) support the translation of global targets to national and local action plans {S1}.

For example, Milestone A1 focuses on increasing the area, connectivity and integrity of ecosystems by five percent. A single numerical objective for these measures will result in different outcomes across dimensions of biodiversity in different locations. For example, genetic and species diversity increase nonlinearly with habitat area, so the expected net gain in these two dimensions when increasing habitat area and connectivity by five percent will vary significantly by region, taxonomic group and the baseline rates of habitat and connectivity change. The milestone of five percent should therefore be considered as a first reference point, against which plans to achieve net gains should be assessed {S1}.

Progress can be made by tracking biodiversity dimensions with essential biodiversity variables (EBVs). EBVs are a compact set of measures describing the state of genomes, species, populations, or ecosystems that provide a common foundation for indicators tracking progress towards Goal A and associated milestones of the GBF {S4}. Indicators for the GBF could be derived from this solid foundation of harmonised data. Data from monitoring networks can support models designed to detect trends in EBVs and identify their drivers at multiple scales. Such models can provide estimates of trends in data-poor areas to support action where *in-situ* observations are limited. Multi-scale models can provide estimates of uncertainty about trends towards the milestones from subnational to global scales and link these to the ecological, social and economic outcomes in Goal B.

7 **Ambitious action is needed immediately and must be sustained over time if we are to put biodiversity on a trend to recovery by mid-century. There is good evidence that while some dimensions of biodiversity recover rapidly following conservation action, many show long-lasting, or time-delayed, changes in response to drivers. These time lags, such**

as for extinctions and restoration outcomes, can be shortened if action is implemented immediately to reduce the effects of drivers of biodiversity loss and restore ecosystems. Crucially, immediate action will also lower the cumulative loss of biodiversity and shorten the time to recovery {S2}.

Milestones for 2030 should account for biodiversity lags inherent to the pathways required to achieve the goals for 2050. The timing of goals and milestones for biodiversity conservation and restoration must account for time lags at several levels: i) in the implementation of action, ii) the change in strength of direct drivers resulting from action on indirect drivers, and iii) the response of different dimensions of biodiversity to changes in drivers {S2}.

The time needed for safeguarding and restoring ecosystem structure, function and resilience is particularly critical for people and communities whose livelihoods and well-being directly depend on these systems and the benefits they provide. As traditional diversity-rich human landscapes are the outcome of the long-term activities of such communities, actively involving and supporting their bottom-up initiatives and customary institutions that safeguard and secure the maintenance of biodiversity can help reach conservation and restoration targets more effectively.

Time-lagged responses of all dimensions of biodiversity stress the importance of monitoring for recovery and restoration outcomes with appropriate reference conditions and baselines. Decisions to prioritize and implement action should be guided by leading indicators (currently not included in the GBF monitoring framework), which are indicators that provide an estimate of expected change and provide early indications of changes in the long-term trends. Using community-based indicators with science-based indicators would enrich knowledge about historical trends and help determine if and which actions result in shortened lag times {S2}.

8 International collaboration should be strengthened, and more focused than it is now, on how to adequately and equitably share the efforts in mitigating drivers of, and reversing, biodiversity loss. The degree of biodiversity change, and relative importance of drivers, vary greatly across scales and from place to place, and drivers in one place can affect biodiversity in another. As a result, responsibilities for addressing both need to be equitably apportioned among countries {S3}.

Global targets of the GBF need to be designed in ways that allow them to be adequately and equitably aggregated and disaggregated across scales, and in particular at the national level, so that the sum of national targets meets the global ambition.

Ecological and evolutionary processes vary over multiple geographic scales from global to local. Drivers of biodiversity loss also vary across scales from global to local, vary in their action across scales and locations, and the source of the driver may be distant from the location of impact (telecoupling). This spatial variation and teleconnections in driver-impact relationships, means that translation of targets and actions from the global scale to regional, national and smaller scales is not linear or direct.

There are three broad classes of responsibility countries shoulder: i) based on the biodiversity within their territorial boundaries, with both national and global aspects, ii) based on drivers originating from the country, also with national and global aspects, and iii) based on differences in national capacities and access to the means of implementation. As a result, countries shoulder different responsibilities which must be taken into account in apportioning actions among countries in meeting global targets. A further consideration is the unequal national capacities of countries to engage in transformative change necessary to curb drivers of biodiversity loss, and the resulting need for cooperation mechanisms, including equitable financial and technological transfers.

The monitoring and indicator framework of the GBF, and periodic stocktakes, should play key roles in quantifying and accounting for these responsibilities {S4}. They should be designed to enable both integration and disaggregation of data, including on resource needs, between national and global scales.

9 Successful implementation of the GBF requires substantial investment in monitoring capacity to allow the detection of trends and the attribution of these trends to drivers across terrestrial, freshwater and marine environments. To do this well we must ensure the supply of, and access to, the data and models that underpin the effective use of indicators as fundamental tools for decision making. Indicators are needed not only to assess progress toward goals and targets, but also to inform strategic planning of actions to most effectively and efficiently achieve outcomes {S4}.

The current monitoring framework of the GBF has focused on the identification of key headline, component and complementary indicators for assessing progress towards targets and goals and for thematic or in-depth analysis of each goal and target. However, the framework largely overlooks the need to assess whether existing biodiversity monitoring systems have the coverage and precision to reliably track change for all regions and attribute the effects of drivers on trends in biodiversity by 2030.

An assessment of the resources needed to build an adequate global biodiversity observation system is needed. Workflows from data to indicators are heavily dependent on a continuous provision of primary data and on a global coordination of monitoring systems, including human capacity to analyse and synthesise data, develop indicators and test them, develop the science and models to do forecasts, and generate the reports and publications required for multiple audiences.

Current biodiversity monitoring and information infrastructures have resulted in the development of indicators for some dimensions of biodiversity change in the GBF; however, monitoring capacities are unequally distributed across the globe resulting in biases towards certain taxa, countries and biomes. Enhancing local and national capacities to generate and access primary data, implement workflows from data to indicators and deliver biodiversity information, will increase the capacity of different stakeholders to produce and use biodiversity indicators in strategic planning and assessment processes, including indicators generated by IPLCs traditional knowledge.

Three complementary approaches to the use of indicators are needed to realise the outcomes of the GBF (Figure 6). The first is to track overall progress towards goals (headline indicators). The second is to progressively improve indicators in order to understand how drivers cause biodiversity change, thereby allowing changes in biodiversity to be attributed to changes in drivers and actions (this should be the main role of component and complementary indicators). The third approach, which is at present almost completely overlooked in the GBF monitoring framework, uses indicators to inform strategic planning (including prioritization) of actions to effectively and efficiently achieve targets and goals (boxes 1, 2 and 3 in Figure 6). For this, we need leading indicators (currently not included in the GBF monitoring framework) which use best-available understanding of these dependencies–at the time a given decision is made–to predict the expected impact of the proposed or implemented actions on biodiversity outcomes. All three of these approaches are critically important and must play complementary roles in an overall adaptive policy and planning framework for the GBF. The set of indicators for monitoring the GBF needs to be expanded to comprehensively cover outcomes, drivers and key interdependencies between these elements.

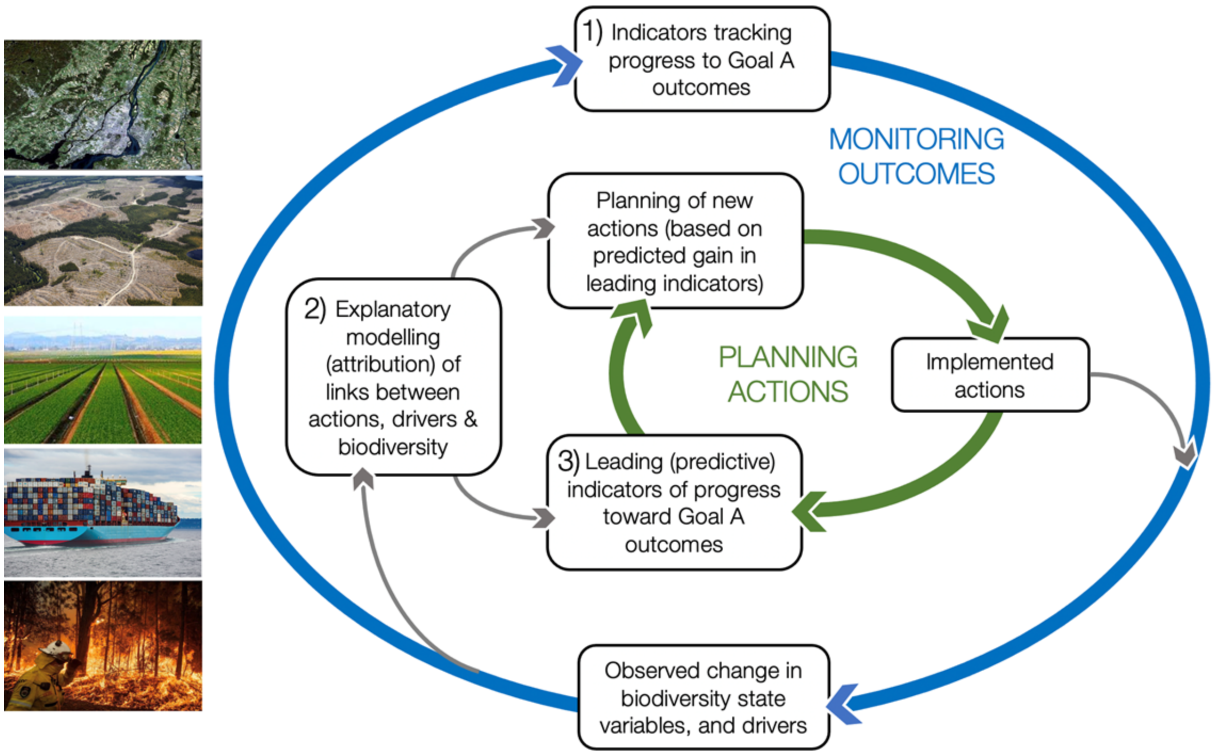


Figure 6. ***The iterative cycle of monitoring and action guided by explanatory models and indicators****. The outer blue cycle refers to the monitoring of actual changes in biodiversity and the updates in indicators used to track progress to Goal A outcomes (box 1). The inner cycle refers to the role of explanatory models (box 2) that use component and complementary indicators that include indicators for drivers and actions and leading indicators (box 3) that incorporate an understanding of the impacts of drivers (attribution) on trends in essential biodiversity variables to guide spatial planning and the prioritization of conservation action.*

Part II

Technical Section 1: Interacting Drivers

High-level findings for the global biodiversity framework

1.1.1 There are no one-to-one linkages between indirect drivers, direct drivers, biodiversity and the actions on these drivers needed to halt and reverse biodiversity loss; rather, a "many-to-many" relationship exists between these. This many-to-many relationship is reflected in the global biodiversity framework (GBF) and implies that the framework needs to be treated as a whole.

1.1.2 Biodiversity loss is caused by all five main direct drivers — land and sea use change, climate change, direct exploitation, invasive alien species and pollution — as well as a broad range of indirect drivers. This means that efforts to halt and reverse biodiversity loss must treat all of these direct and indirect drivers.

1.1.3 Halting and ultimately reversing biodiversity loss requires transformative change – meaning "fundamental, system-wide reorganization across technological, economic and social factors, including paradigms, goals and values, needed for the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development (IPBES 2019)". This implies ambitious actions across the entire scope of the global biodiversity framework.

1.1.4 The different components of biodiversity treated in the global biodiversity framework – ecosystem area, connectivity and integrity; species extinctions, extinction risk and abundance; and genetic diversity of wild and domesticated species – differ in the relative importance of direct drivers, actions required to reduce threats, tools for implementation, time lags in response to changes in drivers, indicators and monitoring requirements. One important implication for the GBF is that Goal A would be clearer if the individual biodiversity components— for example, ecosystem area and ecosystem integrity — were separated in terms of numerical levels of ambition.

1.2 Plain-language summary

This section focuses on the analysis of the relationships between indirect and direct drivers of biodiversity change; the impacts of these drivers on ecosystem, species and genetic levels of biodiversity; and the actions that are required to halt and then reverse the loss of biodiversity based on recent assessments and scientific literature. This analysis is novel because it shows how the pieces of the global biodiversity framework — goals for 2050, milestones for 2030 and action targets for 2030 — fit together.

With four goals for 2050, ten milestones for 2030, twenty-one action targets for 2030 and a large number of headline indicators, it is admittedly difficult to see how all the pieces of the GBF fit together. Indeed, this has led to calls from governments, stakeholders and scientists to substantially simplify the GBF, sometimes emphasising one or a small number of headline objectives (e.g., Mace *et al.* 2018; Rounsevell *et al.* 2020; Watson *et al.* 2020). Díaz *et al*. (2020) presented strong arguments for why the GBF should cover multiple dimensions of biodiversity and nature's contributions to people (NCP). The Global Biodiversity Outlook 5 (GBO 5, Secretariat for the Convention on Biological Diversity (SCBD) 2020) and IPBES Global Assessment (IPBES 2019) presented strong arguments for why actions to achieve the 2050 vision should cover a wide range of indirect and direct drivers and, in particular, address the underlying causes of biodiversity loss, such as unsustainable production and consumption, lack of resources and capacity for conservation and restoration, and subsidies that are harmful for biodiversity (Dempsey *et al*. 2020; Sumaila *et al.* 2021). These analyses have shown that focusing on a single dimension of biodiversity, a single dimension of NCP or a single action will not ensure the achievement of the 2050 vision, and could well lead to perverse outcomes for biodiversity and people. The GBF has embraced this complexity, and with it the inherent difficulties that accompany this complexity.

Detailed analyses of how all the pieces of the GBF fit together are lacking both in the scientific literature and the documents furnished by the Convention on Biological Diversity (CBD) in support of the Open-ended Working Group (OEWG) discussions. There is, however, good evidence with which to build such analyses. There are thorough assessments of trends in biodiversity, indirect drivers and direct drivers over the last decades, as well as progress in achieving the 2020 Aichi Targets of the CBD (IPBES 2019; SCDB 2020). There are also increasingly well-developed analyses of future development pathways and their consequences for biodiversity — in particular scenarios of positive futures that resemble CBD's 2050 vision (IPBES 2019; Leclère *et al.* 2020;

SCBD 2020; Williams *et al.* 2021). These analyses are highly pertinent for the GBF, but have not explicitly addressed the structure and wording of the GBF. There is a reasonably abundant scientific literature focusing on goals and targets of the GBF. However, much of this has focused on single targets, goals or milestones (e.g., Jones *et al.* 2018; Visconti *et al.* 2019; Essl *et al.* 2020; Rounsevell *et al.* 2020; Strassburg *et al.* 2020). Even studies with broader analyses have only covered relatively limited aspects of the GBF. For example, Díaz *et al.* (2020) focused on goals and milestones for biodiversity and nature's contributions to people and Nicholson *et al.* (2021) focused on the ecosystem level goals and associated targets. In addition, much of the literature expressly addressing issues relevant to the GBF can only be applied with considerable caution and careful interpretation to the wording or numerical elements of the goals, milestones and targets. For example, Strassburg *et al.* (2020) examined the benefits for biodiversity of restoring "converted" ecosystems to "natural ecosystems" (see also Section 5), and this has been used to justify quantitative elements of Target 2 on restoration of degraded ecosystems (CBD/SBSTTA/24/3/Add.2). But since "converted" is not the equivalent of "degraded", this has led to considerable confusion about the applicability of this study to Target 2 (see more detailed discussion in Section 5).

Not fully addressing the complexity of the GBF in discussions and negotiations comes with two risks. The first risk is that there will be a piecemeal approach to analysing each of the components of the GBF individually, and the synergies and trade-offs between the components will not be taken into account. In this case the sum of the parts may not equal the whole. The second danger is that some components of the GBF will be set at ambitious levels and highlighted at the expense of others that are less easily communicated to politicians and the public, or more difficult to implement. In this case, weak ambition for key targets or components of targets could greatly undermine the benefits of high ambition on those that are highlighted (Visconti *et al.* 2019; Díaz *et al.* 2020).

Our analysis is broken down into five broad categories:

- Sections 1.3.1 and 1.3.2 give an overview of the relationships between action targets of the GBF (especially Targets 1-10) and the direct drivers of biodiversity change, and the relationship of these drivers to ecosystem, species and genetic levels of biodiversity embodied in Goal A and associated milestones. This analysis provides a more detailed view of the linkages in Figure 2 , and how these linkages are addressed in the narratives provided by the

CBD that describe the targets.

- Sections 1.3.3 and 1.3.4 provide more detailed analysis of the direct and indirect drivers of biodiversity change with a focus on the relative contributions of the five main direct drivers to biodiversity loss, the types of indirect drivers and their interactions. This analysis shows that the relative importance of drivers varies from place to place and across ecosystems, species and genetic levels of diversity, but that degradation of biodiversity is caused by multiple indirect and direct drivers. This means that actions should address this multiplicity of drivers.
- Section 1.3.5 highlights actions that have been successful in slowing or reversing biodiversity loss, with examples from coral reefs, Amazonian rainforest and critically endangered species. This analysis shows that success is typically the result of multiple concerted and context dependent actions targeting a wide range of direct and indirect drivers.
- Section 1.3.6 analyses the underlying pathways that can achieve positive futures for biodiversity based on recent scenario and modeling research. This analysis suggests that strong conservation and restoration actions cannot alone halt and reverse biodiversity loss: these actions must be accompanied by transformative changes in production and consumption, governance, finance and capacity. They also highlight the imperative of keeping global warming at or below 1.5°C.
- Section 1.3.7 examines how the different components of the biodiversity goals and milestones in the GBF differ in the relative importance of direct drivers, actions required to reduce threats, tools for implementation, time lags in response to changes in drivers and requirements for indicators and monitoring. This analysis suggests that treating the different components separately in terms of ambition, especially numerical targets could help clarify discussions of the GBF.

1.3 Statements summarising the evidence

1.3.1 There are no one-to-one linkages between indirect drivers, direct drivers, biodiversity and the actions on these drivers needed to halt and reverse biodiversity loss, rather, a "many-to-many" relationship exists between these. This many-to-many relationship is reflected in the global biodiversity framework and means that the framework needs to be treated as a whole in order to be successful.

This many-to-many relationship is illustrated in Figure 1.1, which provides further detail supporting Figure 2 by explicitly showing the links between Targets (actions) and direct drivers, the links from drivers to the individual dimensions of biodiversity in Goal A, interactions between dimensions of biodiversity, and ties to Goals B, C and D. In fact, based on the driver-impact contributions assessed by IPBES (2019, Figure 3 of this report) no single target makes more than a 10-15% contribution to achievement of any one biodiversity milestone of the GBF (Figure 1.2), indicating the need to address all targets in an integrated fashion and with high ambition (Díaz et al. 2020).

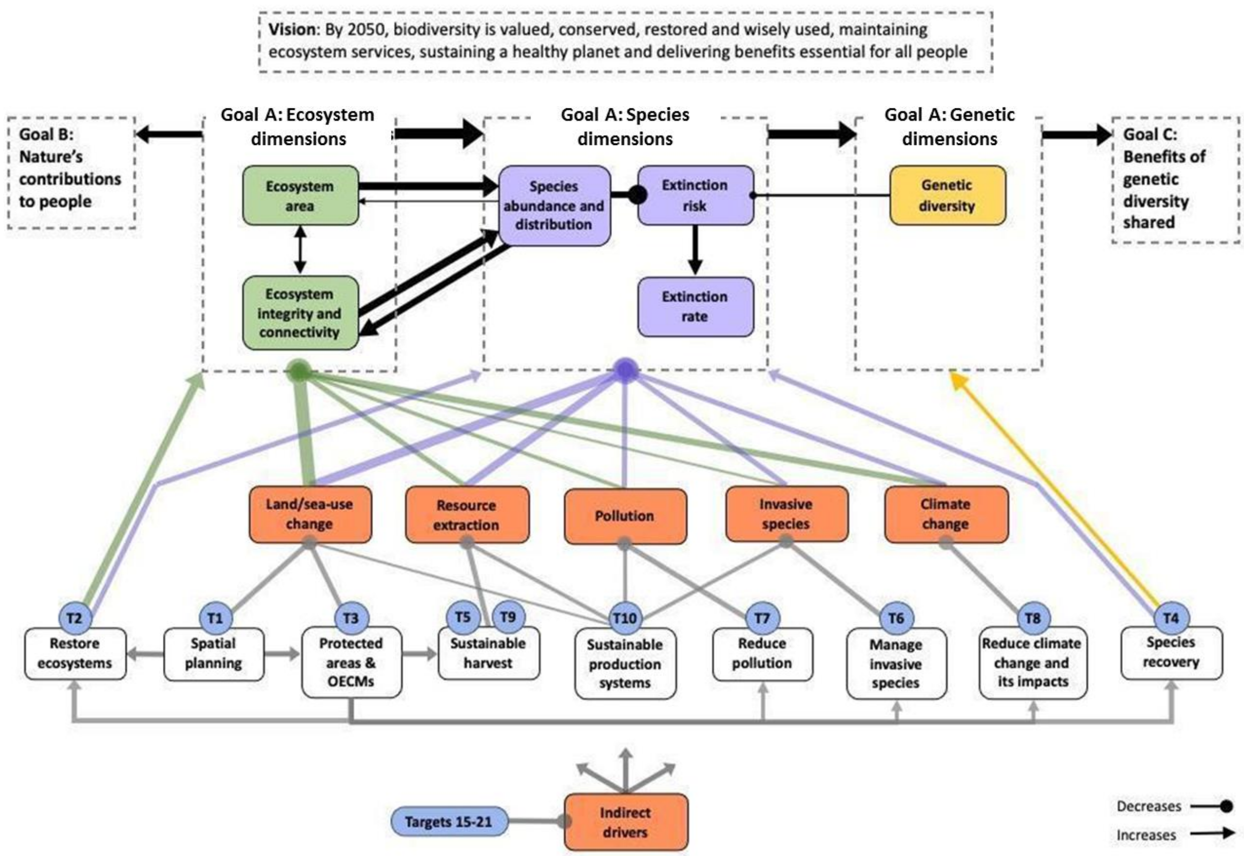


Figure 1.1 *Relationship between outcomes, components of biodiversity, direct drivers and targets of the GBF. This figure shows the relationship between outcomes (Goals and Goal A components, in dashed boxes), components of biodiversity (A1 area, integrity and connectivity of natural ecosystems, green; A2 abundance and distribution of populations of species, species extinction rate and species extinction risk, purple; and A3 maintenance of genetic diversity, gold boxes), direct drivers (orange boxes) and targets (blue circles, where T1 is Target 1, and so forth). See Table 1.1 for wording of goal A, milestones and targets. Black arrows depict relationships amongst goals and goal A components highlighting the role of biodiversity (Goal A) in sustaining ecological functions, ecosystem services and Nature's contributions for people (Goal B) and the genetic diversity that underpins Goal C. Relationships between dimensions of biodiversity, direct drivers and targets are shown in coloured and grey arrows where arrow weight is relative to impact in Figure 1.3 (also in Figure 2 , see Appendices 1.1 and 1.2 for documentation). Some targets act*

directly on a given dimension of biodiversity (e.g., T4 on species recovery directly affects species abundance and distribution), while others act to reduce a driver or its impact (e.g., T6 on invasive alien species), thus benefiting biodiversity indirectly. Many action targets interact, illustrated through T3 (on protected areas and other effective area-based conservation measures), which is likely to affect other targets through strengthened resources and incentives to manage drivers such as land/sea use change, invasive alien species management, restoration and species recovery within protected areas (PAs) and other effective area-based conservation measures (OECMs).

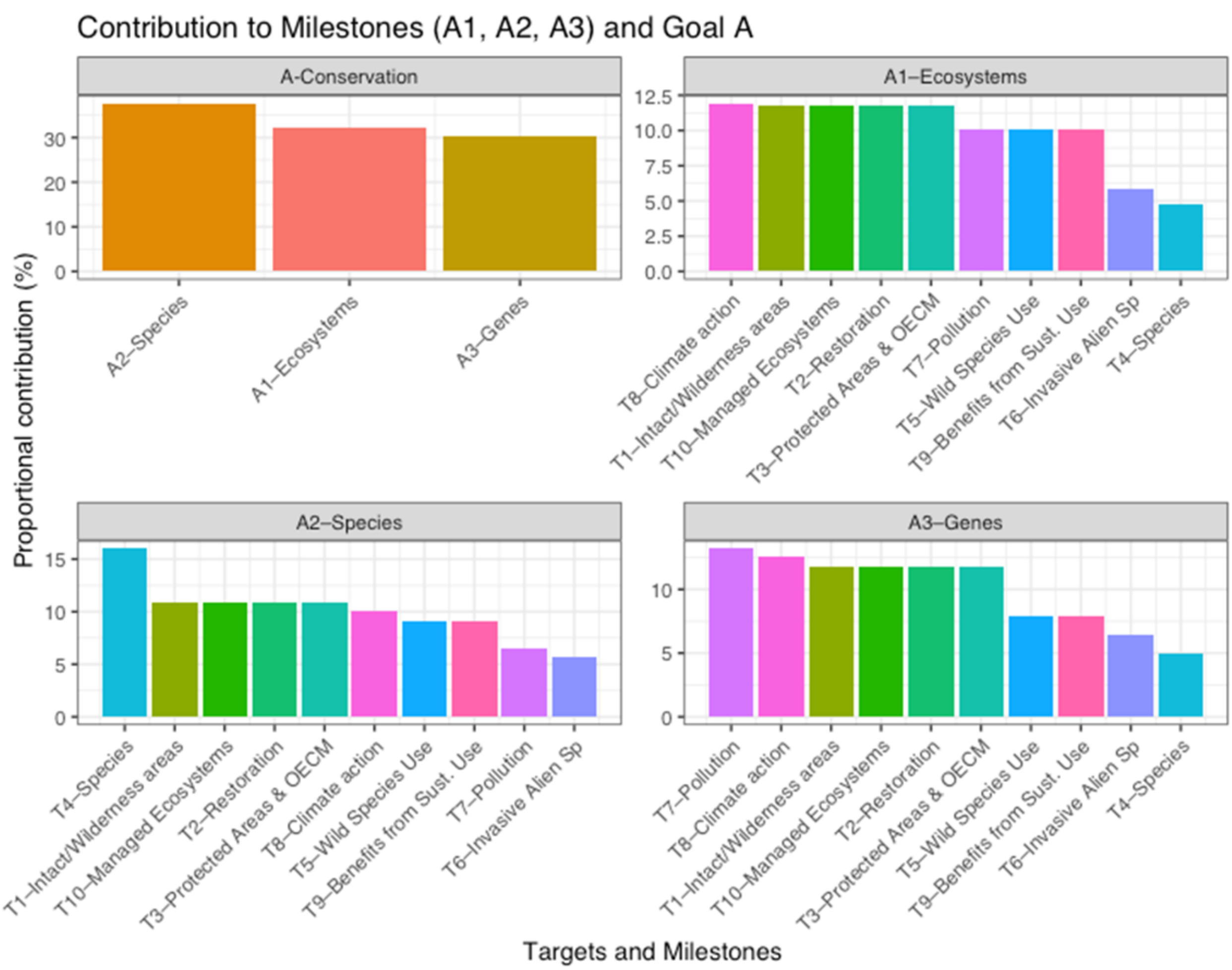


Figure 1.2 *The proportionate contribution of Targets 1-10 to Milestones A1, A2 and A3, and of these milestones to Goal A, in Figure 2 (see Appendix 1.1 for calculations). The sum of proportions in each subfigure adds to 100%.*

Note that Figure 1.1 does not include the details of links with Targets 14-21 which address actions on indirect drivers (these are treated later in Sections 1.3.4 and 1.3.6). This figure highlights the many-to-many relationship between the actions in the Targets and outcomes for biodiversity in Goal A, and hence the need for concerted action instead of individual but disjointed responses.

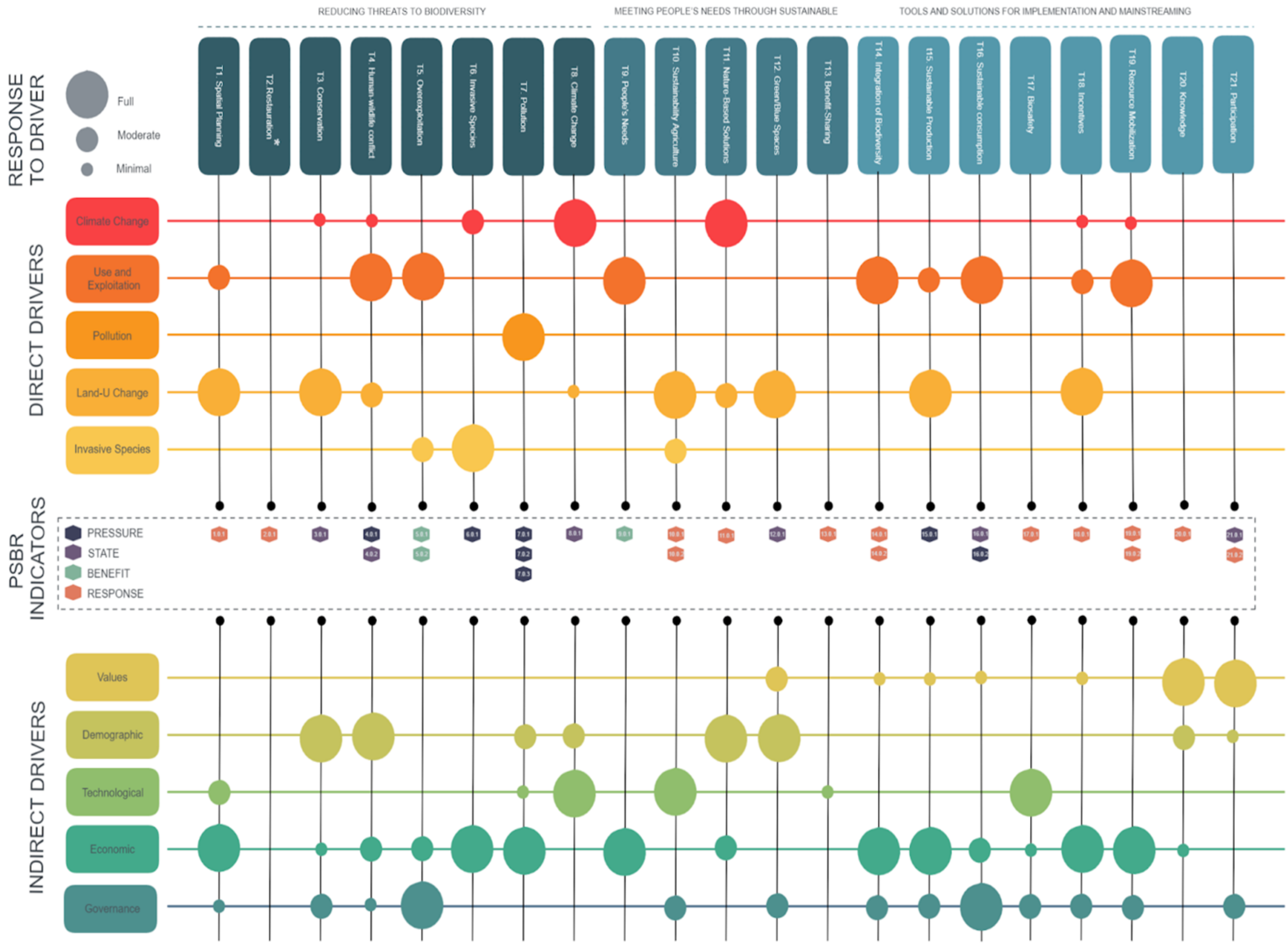
Table 1.1 *Goal A for 2050, Milestones for 2030 and Targets 1-10 which are actions that directly influence direct drivers of biodiversity loss. From the first draft of the post-2020 global biodiversity framework version CBD/WG2020/3/3 (5 July 2021).*

Goal A 2050	The integrity of all ecosystems is enhanced, with an increase of at least 15 per cent in the area, connectivity and integrity of natural ecosystems, supporting healthy and resilient populations of all species, the rate of extinctions has been reduced at least tenfold, and the risk of species extinctions across all taxonomic and functional groups, is halved, and genetic diversity of wild and domesticated species is safeguarded, with at least 90 percent of genetic diversity within all species maintained.
Milestone A.1 2030	Net gain in the area, connectivity and integrity of natural systems of at least 5 per cent.
Milestone A.2 2030	The increase in the extinction rate is halted or reversed, and the extinction risk is reduced by at least 10 per cent, with a decrease in the proportion of species that are threatened, and the abundance and distribution of populations of species is enhanced or at least maintained.
Milestone A.3 2030	Genetic diversity of wild and domesticated species is safeguarded, with an increase in the proportion of species that have at least 90 per cent of their genetic diversity maintained.
Target 1	Ensure that all land and sea areas globally are under integrated biodiversity-inclusive spatial planning addressing land- and sea-use change, retaining existing intact and wilderness areas
Target 2	Ensure that at least 20 percent of degraded freshwater, marine and terrestrial ecosystems are under restoration, ensuring connectivity among them and focusing on priority ecosystems
Target 3	Ensure that at least 30 percent globally of land areas and of sea areas, especially areas of particular importance for biodiversity and its contributions to people, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.
Target 4	Ensure active management actions to enable the recovery and conservation of species and the genetic diversity of wild and domesticated species, including through ex situ conservation, and effectively manage human-wildlife interactions to avoid or reduce human-wildlife conflict.
Target 5	Ensure that the harvesting, trade and use of wild species is sustainable, legal, and safe for human health.
Target 6	Manage pathways for the introduction of invasive alien species, preventing, or reducing their rate of introduction and establishment by at least 50 per cent, and control or eradicate invasive alien species to eliminate or reduce their impacts, focusing on priority species and priority sites.
Target 7	Reduce pollution from all sources to levels that are not harmful to biodiversity and ecosystem functions and human health, including by reducing nutrients lost to the environment by at least half, and pesticides by at least two thirds and eliminating the discharge of plastic waste.
Target 8	Minimize the impact of climate change on biodiversity, contribute to mitigation and adaptation through ecosystem-based approaches, contributing at least 10 GtCO2e per year to global mitigation efforts, and ensure that all mitigation and adaptation efforts avoid negative impacts on biodiversity.
Target 9	Ensure benefits, including nutrition, food security, medicines, and livelihoods for people especially for the most vulnerable through sustainable management of wild terrestrial, freshwater and marine species and protecting customary sustainable use by indigenous peoples and local communities.
Target 10	Ensure all areas under agriculture, aquaculture and forestry are managed sustainably, in particular through the conservation and sustainable use of biodiversity, increasing the productivity and resilience of these production systems.

1.3.2 While this many-to-many relationship is reflected in the narratives of the Targets in

the global biodiversity framework, many important interactions are overlooked in the narratives, which could compromise their successful implementation.

Figure 1.3 shows how direct and indirect drivers are reflected in the narratives of each of the targets of the GBF (CBD/SBSTTA/24/INF/21). When taken across all GBF documents, the narratives are richer than this single document that we used for the analysis. This analysis is intended to show the utility of this type of analysis of the relationships between indirect drivers, direct drivers and the 21 targets of the GBF. For example, the narrative on invasive alien species (IAS, Target 6) is naturally centered on reducing threats to biodiversity from IAS, but also addresses the effects of climate change on IAS distributions and focuses on economics (especially international trade) as the primary indirect driver. The narrative for IAS pays less attention to the important roles that values, land and sea use and governance play in controlling IAS impacts on biodiversity (see example in 1.3.5). As another example, most targets pay little attention to climate change, climate mitigation and climate adaptation even though all of these are known to strongly interact with climate issues (Arneth *et al.* 2020; Pörtner *et al.* 2021). Comparing the narratives with knowledge of the past and future importance of drivers could help to better frame the targets and set levels of ambition (Arneth *et al.* 2020).



REDUCING THREATS TO BIODIVERSITY
MEETING PEOPLE'S NEEDS THROUGH SUSTAINABLE
TOOLS AND SOLUTIONS FOR IMPLEMENTATION AND MAINSTREAMING
RESPONSE TO DRIVER
Full
Moderate
Minimal
T1 Spatial Planning
T2 Restauration
T3 Conservation
T4 Human wildlife conflict
T5 Overexploitation
T6 Invasive Species
T7 Pollution
T8 Climate Change
T9 People's Needs
T10 Sustainability Agriculture
T11 Nature-Based Solutions
T12 Green/Blue Spaces
T13 Benefit-Sharing
T14 Integration of Biodiversity
T15 Sustainable Production
T16 Sustainable consumption
T17 Biosafety
T18 Incentives
T19 Resource Mobilization
T20 Knowledge
T21 Participation
DIRECT DRIVERS
Climate Change
Use and Exploitation
Pollution
Land-U Change
Invasive Species
PSBR INDICATORS
PRESSURE
STATE
BENEFIT
RESPONSE
INDIRECT DRIVERS
Values
Demographic
Technological
Economic
Governance

Figure 1.3. *Analysis of the direct and indirect drivers as addressed in the narratives of the 21 targets of the GBF. Targets are represented in the columns and direct and indirect drivers in the rows, the size of the circle indicates if a driver is included in the narrative of the target as described in the document CBD/SBSTTA/24/INF/21, the size of the circle indicates if a driver is included in the narrative as a main issue (big circle, full response) or a minor issue (small circle, minimal response). Headline indicators are shown in the center of the figure and are discriminated using the Pressure, State, Response, Benefit framework (Sparks* et al. *2011).*

1.3.3 Biodiversity loss in all dimensions of biodiversity, across all realms and in all regions is caused by all five main direct drivers — land and sea use change, climate change, direct exploitation, invasive alien species and pollution. The relative impacts of direct drivers on biodiversity in the recent past, as well as levels of uncertainty in attribution of biodiversity change to these drivers are well documented. Therefore actions to reduce biodiversity loss will need to address all of these drivers to be effective.

1.3.3.1 The IPBES Global Assessment (IPBES 2019) summarised the relative importance of the five main direct drivers across dimensions of biodiversity (Figure 1.4), regions, realms (land, freshwater and marine) and biodiversity indicators, based on scientific evidence as well as evaluation by indigenous peoples and local communities (IPLCs). In every case, all five direct drivers (and a variety of less well categorised additional drivers) are known to have important impacts on biodiversity. Local actions and conservation of individual species may be successful without treating the full range of drivers, but at larger scales and across multiple dimensions of biodiversity this means that actions on a single direct driver will be insufficient to broadly slow and ultimately reverse biodiversity loss.

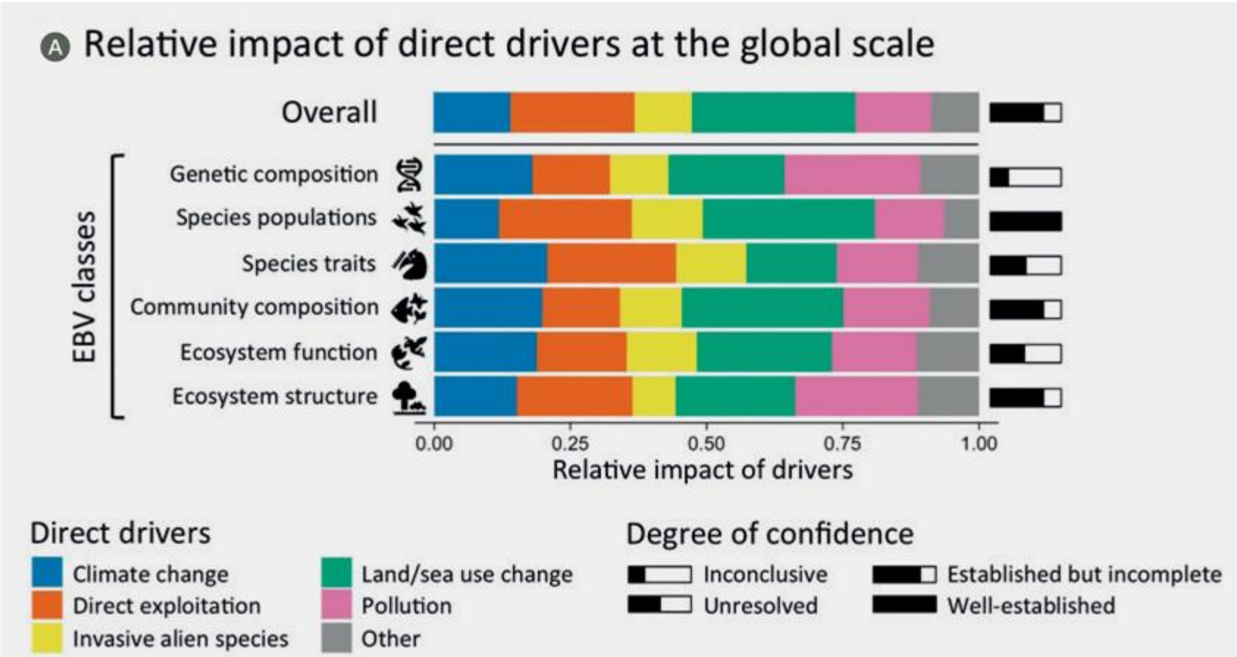


Figure 1.4 *Relative importance of drivers across several levels of biodiversity. Confidence levels in attribution are indicated by the black bars. (*Source*: IPBES 2019, Figure 2.2.22A; see additional figures summarising across regions, realms and indicators in Section 2.2.5 of IPBES 2019).*

1.3.3.2 Interactions between direct drivers are well documented for some specific regional contexts (e.g., tropical deforestation), ecosystem types (e.g., coral reef degradation), and components of biodiversity (e.g., bird extinctions). We lack a more complete understanding of the full set of drivers and their interactions because of the focus of the bulk of research and monitoring on specific drivers and ecosystem types (IPBES 2019). The interactions between drivers are context-dependent therefore summaries made at global scales should not be directly transcribed to specific contexts. The implication of this is that actions are needed on all direct drivers to achieve ambitious outcomes for biodiversity, but that actions need to be adapted to the local context (see also Section 3).

1.3.4 A broad range of indirect drivers contribute to biodiversity loss. Indirect drivers are more numerous and difficult to categorize. In addition causal links to biodiversity change are more distal, uncertain and slower to play out than direct drivers. As a result, the relative contributions of indirect drivers to biodiversity change at global scales have been less well quantified than for direct drivers.

1.3.4.1 Biodiversity loss is mediated by a wide range of interacting indirect drivers (Table 1.2).

The classification of indirect drivers is not consistent in the literature, or even within and across IPBES assessments. In some cases, indirect drivers also fall into a grey zone covering both direct and indirect effects on biodiversity. This issue of classification for indirect drivers is in contrast to direct drivers where the five main classes of direct drivers of biodiversity loss at the global scale have been treated relatively consistently since the *Millennium Ecosystem Assessment* (2005). This hinders consistent analysis and quantification of the relative impacts of indirect drivers on biodiversity. Many of the indirect drivers in Table 1.2 are explicitly addressed in the targets of the GBF, or in their narratives (see Figure 1.3). Some important direct drivers are not covered such as freshwater abstraction, nor are some key indirect drivers such as human population growth, or armed conflicts.

1.3.4.2 In many cases, it is difficult to quantitatively attribute biodiversity loss to specific indirect drivers. There is, however, a good qualitative understanding of the effect of indirect drivers on changes in biodiversity at global scales and even better understanding at local scales (IPBES 2019). In general, there is a need to identify the mechanisms through which indirect drivers trigger direct drivers thereby resulting in biodiversity loss or affecting biodiversity. This has been done for some drivers, such as food systems (e.g., Behrens *et al.* 2017; Crenna *et al.* 2019; Henry *et al.* 2019). Indeed, food systems stand out as the primary driver of biodiversity loss on land and in the sea (IPBES 2019; SCBD 2020). However, the production end of food systems, primarily agriculture, aquaculture and fisheries, defies simple classification into direct and indirect drivers (IPBES 2019, see Table 1.2), which complicates the parsing of the GBF targets related to them (see Figure 1.1 and Figure 2). Agriculture — through land use change, pollution from fertilizers and pesticides, abstraction of freshwater, and large contributions to climate change — is the primary driver of biodiversity loss on land (IPBES 2019). Fisheries — through direct exploitation of marine life and habitat degradation due to destructive fishing practices such as trawling — are the primary driver of biodiversity loss in the sea (IPBES 2019, see example of impacts of trawling in Appendix 1.4). As such, sustainable diets, agriculture practices and fishing practices, as well as decreasing food waste systematically stand out as primary levers for reducing threats to biodiversity (Targets 9, 10, 16; IPBES 2019, see also Appendix 1.4).

Table 1.2 *Main categories of indirect drivers treated in the IPBES Global Assessment (IPBES 2019, from Table of contents of Chapter 2).*

Indirect Drivers	Values	· Different social groups hold different values · Values of nature are rapidly changing
	Demographic	· Human population dynamics · Migration · Urbanization · Human Capital
	Technological	· Traditional technologies (indigenous and local knowledge) · Technological changes in primary sectors (with direct uses of nature) · Technological changes, and trade-offs, within urbanization and industry
	Economic	· Structural transition · Concentrated production · Trade · Financial flows
	Governance	· Market interactions · Local community coordination · States o Adjusting development policies o Increasing conservation policies o Equity considerations · Global coordination
Indirect-to-Direct Drivers	Fisheries, aquaculture and mariculture	
	Agriculture and grazing (crops, livestock, agroforestry)	
	Forestry (logging for wood and biofuels)	
	Harvesting (wild plants and animals from seascapes and landscapes)	
	Mining (minerals, metals, oils, fossil fuels)	
	Infrastructure (dams, cities, roads)	
	Tourism (intensive and nature-based)	
	Relocations (of goods and people)	
	Restoration	
	Illegal activities with direct impacts on nature	

Analyses of the contributions of a broad range of indirect drivers to biodiversity loss are lacking. For the GBF, this means that it is difficult to predict the quantitative implications of individual actions on indirect drivers in Targets 14-21 for biodiversity, and even more difficult to predict how multiple actions will interact. We do, however, have a reasonably good qualitative understanding. Figure 1.5 shows one attempt to qualitatively trace the effects of several indirect drivers, through direct drivers and finally to impacts on biodiversity (IPBES 2019). In another example, Isbell *et al*. (in review) used expert elicitation to estimate the relative importance of direct drivers and indirect drivers on biodiversity. For direct drivers, the results are very coherent with the literature analysis carried out in the IPBES. For indirect drivers, biodiversity experts indicated that the two primary indirect drivers of biodiversity loss have been unsustainable production and consumption and human population growth, with more modest contributions of governance and trade, and a smaller contribution of technology.

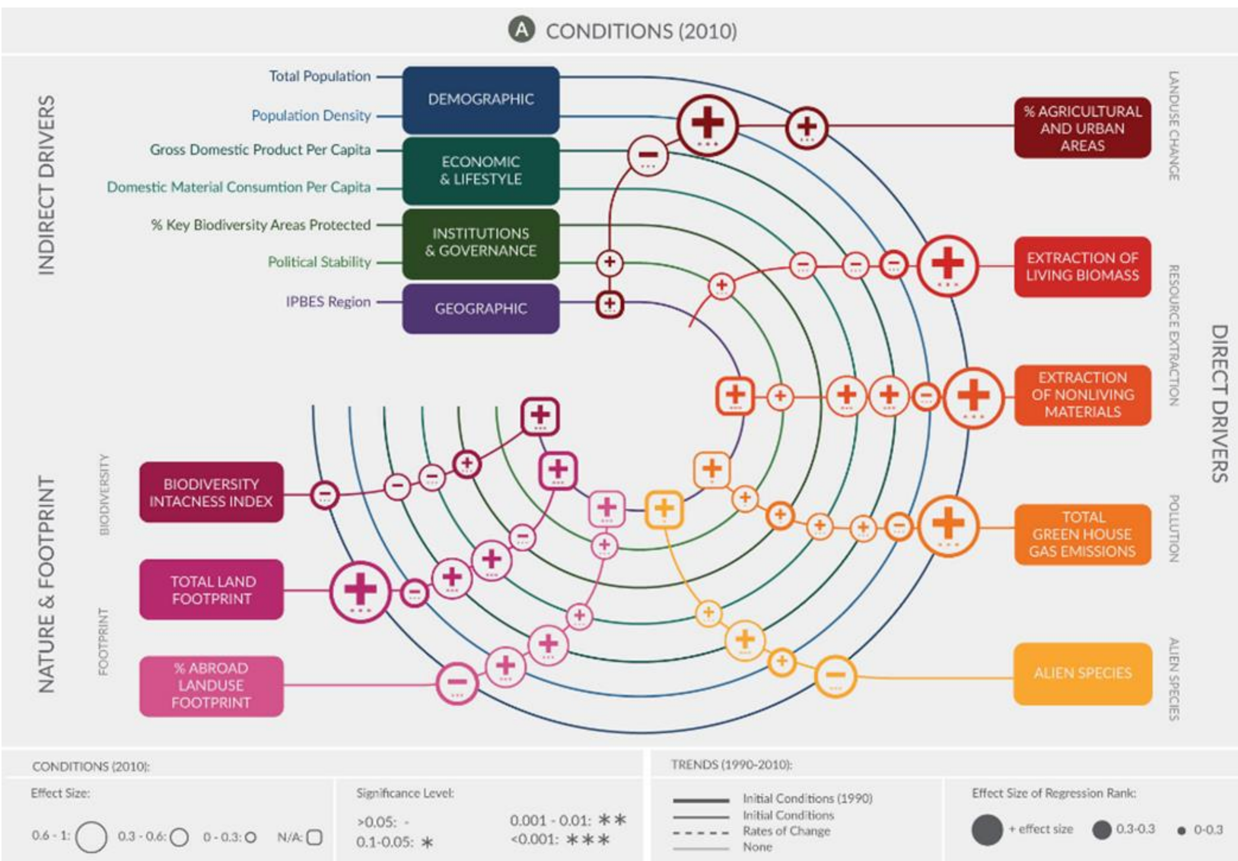


Figure 1.5 *Interactions between some indirect drivers, direct drivers and measures of biodiversity change. Correlations between trends of change in country values for 1990-2010. Multiple regression analysis was used as a way of summarising correlations for current conditions, while regression trees were used for the correlations of the trends (*Source*: IPBES 2019, Figure 2.1.17A).*

1.3.5 Most examples of positive outcomes for biodiversity require multiple actions to reduce threats from direct drivers and to address the underlying indirect drivers. There is

rarely a "silver bullet" through which a single action is sufficient to halt the loss of biodiversity.

1.3.5.1 Positive outcomes for biodiversity resulting from actions that reduce multiple pressures from direct drivers, coupled with actions on indirect drivers are well documented for many cases (Box 1.1), as are negative outcomes when actions are ineffective or weak (IPBES 2019). For example, when direct and indirect drivers are identified and pressures from these drivers greatly reduced, species populations can rebound even from very low levels (Box 1.1), albeit with greatly reduced genetic diversity, sometimes with very long temporal lags and requiring substantial mobilisation of resources (McCarthy *et al.* 2008; Young *et al.* 2014; Hoffmann *et al.* 2015; Bolam *et al.* 2021; see also Section 2). Similar responses are seen in ecosystem integrity to reducing pressures from direct drivers, although recovery may be slow, incomplete and uncertain (Box 1.1, IPBES 2019; Nicholson *et al.* 2021; see Section 2).

1.3.5.2 In many cases, there are strong synergies between actions, making acting on all of them together much easier than acting on them individually (IPBES 2019). On the other hand, situations in which all actors are winners from actions to protect and restore biodiversity are rare, so finding lasting and equitable solutions is often complex (IPBES 2019).

1.3.5.3 Climate change will pose a significant problem in this respect because emissions and climate system lags translate into warming and other aspects of climate change increasing to at least 2050 and beyond (for some slow-responding elements in the climate system such as glacier loss and sea level rise), even for highly ambitious mitigation targets (IPCC 2019; Arneth *et al.* 2020; see also Section 2). There are also synergistic impacts with other drivers that can amplify the impacts of climate change – for example, habitat fragmentation greatly reduces the capacity of species to shift their ranges due to climate change, thereby increasing extinction risk.

Box 1.1 *Examples of interactions between actions, targets, indirect drivers, direct drivers and outcomes for biodiversity for tropical coral reefs, humid tropical forests and avoiding extinctions for birds and mammals.*

Tropical Coral Reefs

Coral reefs are at high risk of collapse worldwide, threatening both biodiversity and nature's contributions to people (NCP; Bland *et al.* 2017; Hughes *et al.* 2017; Obura *et al.* 2021; Uribe *et al.* 2021). They are threatened by multiple drivers, in particular climate change, but also overfishing and nutrient/pollution run-off from terrestrial systems. Addressing these drivers will require coordinated action, nested under multiple targets, across multiple sectors (see Obura *et al.* 2021, especially Table 3). Actions to achieve Goal A (increasing integrity of coral reefs and populations of important species) also benefit Goal B (NCP such as coastal protection and tourism value). Targets interact to reduce drivers: for example marine protected areas (MPAs) and sustainable management of wild species both reduce over-fishing, with benefits to fish populations, fisheries and fishers (see Appendix 1.5 for a more detailed list of actions).

Coral reef example: key relationships between ecosystem, drivers, goals and targets

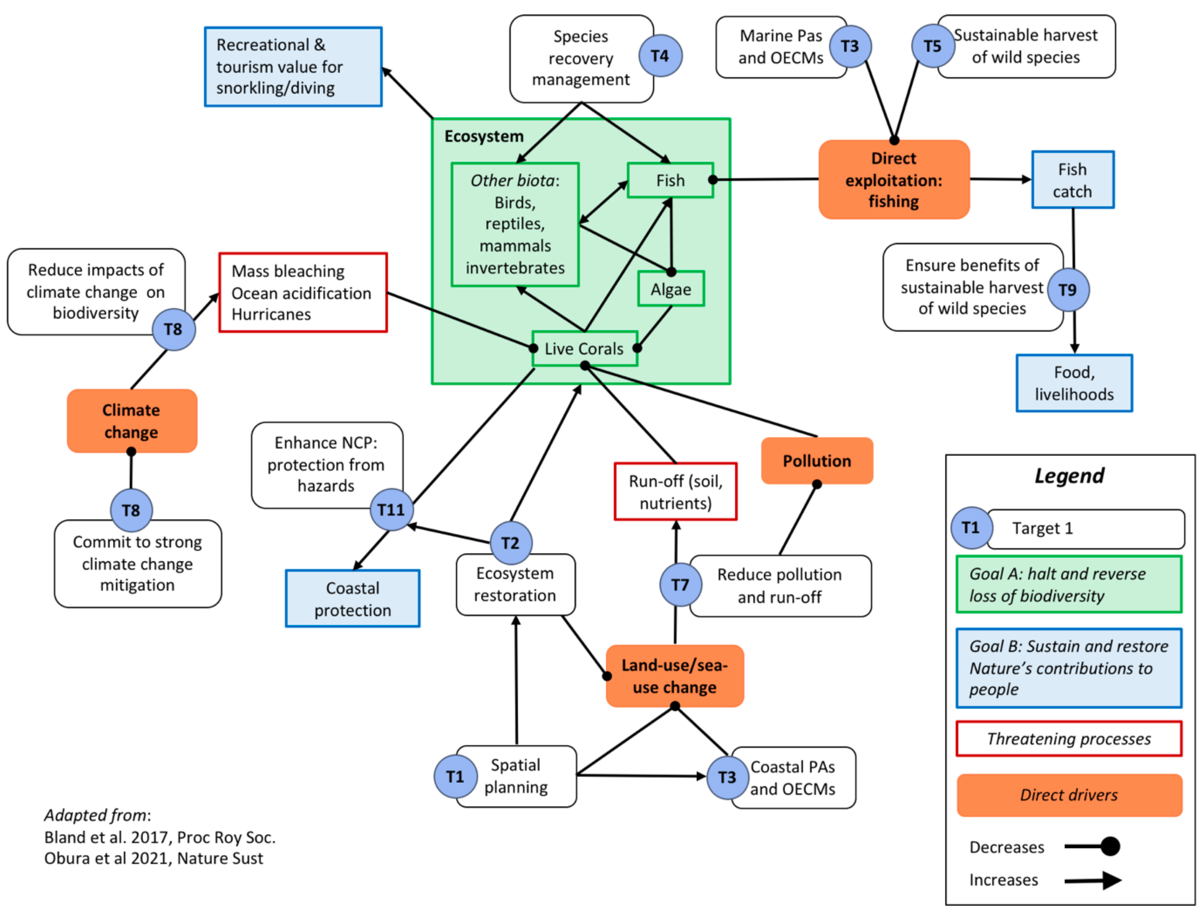


Figure 1.6 *Direct drivers, actions and related targets of the GBF (Targets 1-11) and impacts on various components of biodiversity in tropical coral reefs. See Table 1.1 for wording of Goal A and Milestones, as well as Targets 1-10 (note: Target 11, maintain and enhance nature's contributions to regulation of air quality, quality and quantity of water, and protection from hazards and extreme events for all people). See Appendix 1.5 for a more detailed list of actions. Abbreviations: 'PA' – Protected Area; 'OECM' - Other*

Effective Conservation Measures; 'NCP" - Nature's Contributions to People.

Box 1.1. *continued*

Tropical Rainforests of the Amazon basin

Tropical rainforests in the Amazon are at risk of shifting regimes toward drier, hotter conditions and appear to have recently become a net carbon source (Gatti *et al.* 2021). Both direct and indirect, and often interacting drivers contribute to dynamics of forest fragmentation and loss with declining biodiversity, but there is evidence for actions to conserve forests and their biodiversity. These include: establishing and enforcing protected areas (PAs), including lands under indigenous management; maintaining strong legal protections against encroachment by mining and industrial agriculture in PAs; strengthening and enforcing logging, hunting and sustainable use laws; and fire monitoring with on-the-ground follow-up to mitigate land use change. While changes in governance toward relaxing protection and enforcement have been shown to increase land grabbing, which catalyses land use change and is itself associated with the expansion of commodities and infrastructure, strong protections sharply reduce deforestation rates. Transformative changes to a sustainable bio-economy are needed to mitigate strong and global pressures from commodity markets and infrastructure. These actions include: change in values, monitoring, laws, enforcement, and adaptive co-management.

Box 1.1 *continues*

Box 1.1 *continued*

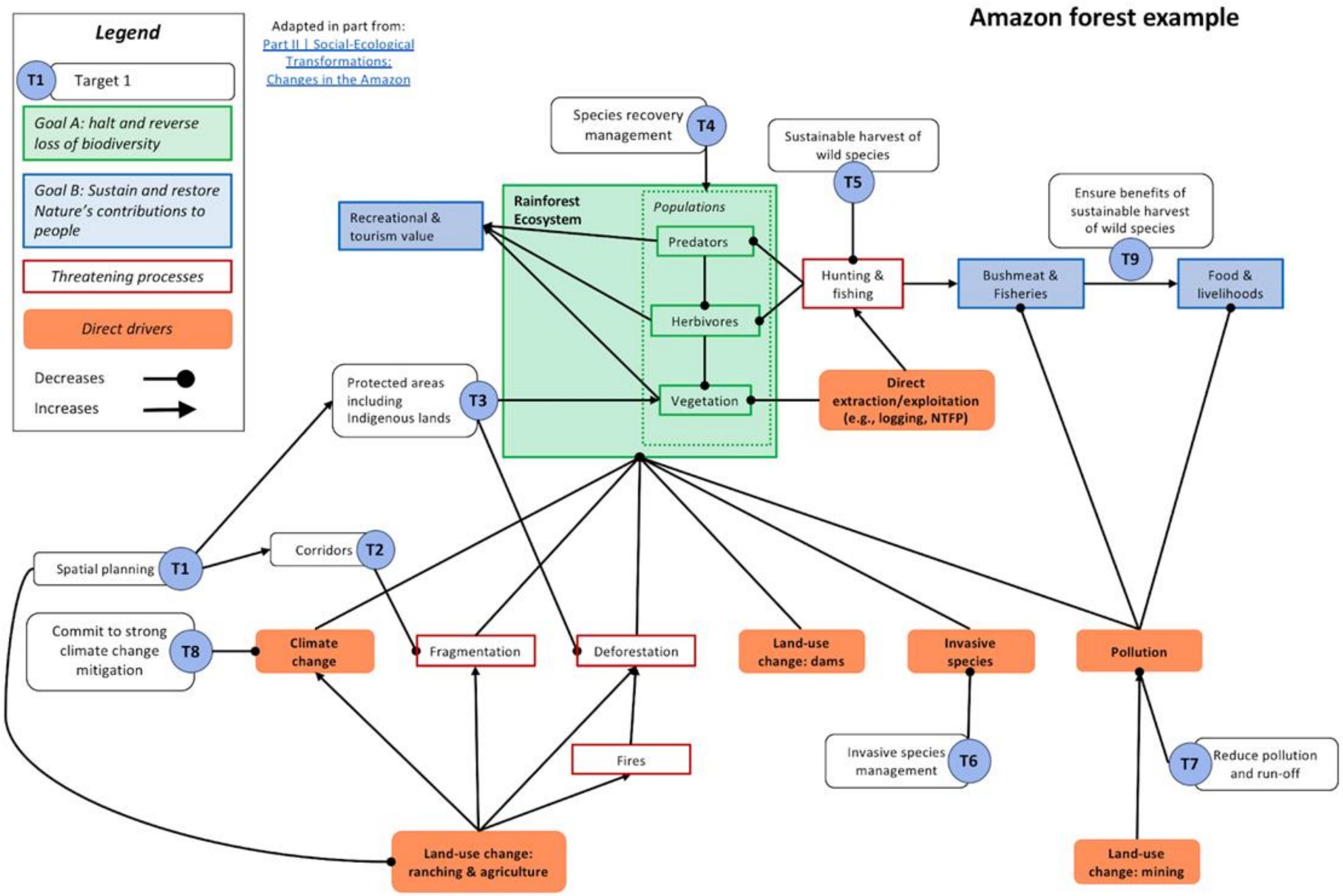


Figure 1.7 *Direct drivers, actions and related targets of the GBF (Targets 1-11) and impacts on various components of biodiversity in Amazonian tropical forests. See Table 1.1 for wording of Goal A and Milestones, as well as Targets 1-10. See Table 1.3 for more detailed explanations of actions.*

Box 1.1 *continued*

Avoided extinctions for threatened birds and mammals

Bolam *et al.* (2021) analyzed the actions that have helped prevent the extinction of 32 bird and 16 mammal species that experts judged would have likely gone extinct without conservation actions over the period 1993-2020. They estimated that extinction rates would have been approximately 2.9 to 4.2 times higher in the absence of these interventions. In most cases, a broad range of concerted actions were needed. Types of interventions were similar between birds and mammals, but their relative importance differed substantially. Control of problematic species and diseases were the most important action for birds: laws controlling hunting and collecting were the most important action for mammals.

It is important to note that invasive alien species (IAS) are not identified as the top-ranked driver of biodiversity loss in any of the different presentations of global biodiversity decline in the IPBES Global Assessment (IPBES 2019). Invasive alien species are, however, the primary single driver of mass bird extinctions on islands, and this highlights the need to take into account local contexts when implementing global targets. For example, over the past 1,000 years, New Zealand has lost 40–50% of its bird species, and over half of these extinctions are attributable to predation by introduced mammals. Eradication of invasive predators, the creation of predator free sanctuaries (Bombaci *et al.* 2018), combined with stringent biosecurity policies, have permitted recovery of a high number of endemic bird species in the country, significantly reducing the risks of future extinctions. More broadly, eradications on islands have permitted the restoration of 236 native terrestrial insular species (596 populations) and in the future eradications could benefit 95 percent of the 1,189 threatened island species (Bombaci *et al.* 2018).

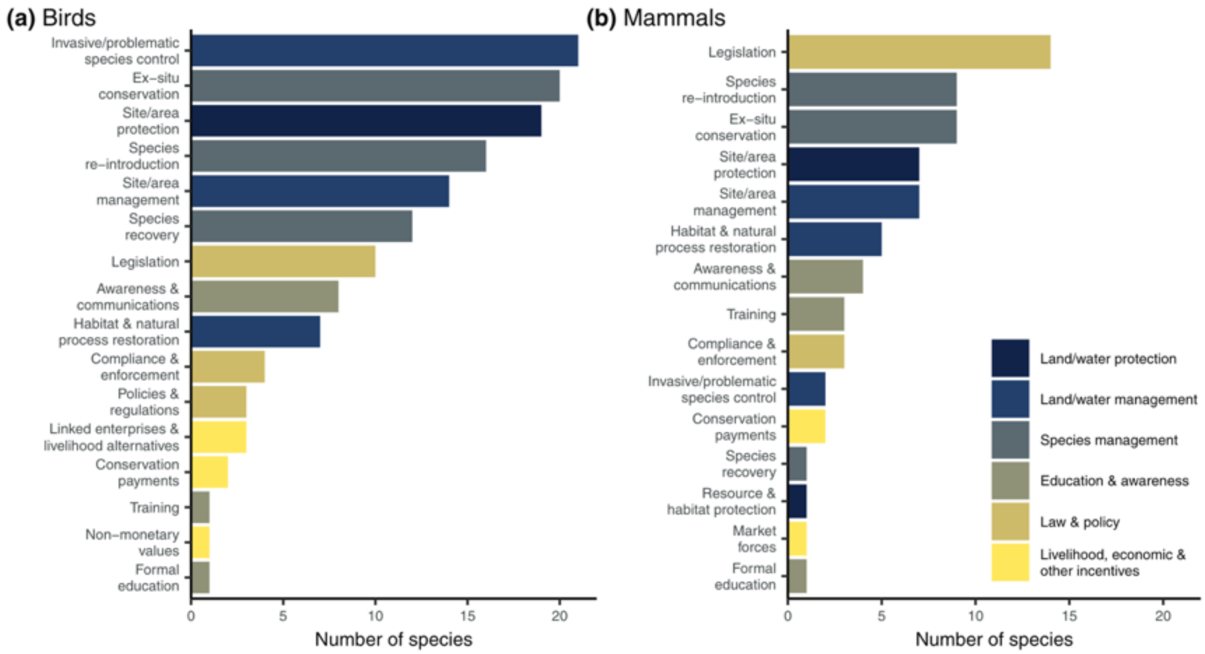


Figure 1.8 *Conservation actions for (a) bird and (b) mammal species for which extinction is judged to have been likely to have occurred in the absence of conservation action during the period 1993–2020. Expert elicitation was used to judge the likelihood of extinction. The total number of bird species is 32 and mammal species is 16. Actions are taken from the IUCN action classification scheme level 2, while colours denote level 1* (*Salafsky* et al. *2008;* Source*: Bolam* et al. *2021).*

The benefits of species conservation plans have also been compared for species that are not on the verge of extinction (Jellesmark *et al*. in press, Figure 1.9). It is possible to compare "treated" populations, i.e., those that enjoyed targeted conservation interventions, and "control" populations in the same taxonomic group, and geographic region, but that were not subject to conservation interventions. By matching target and control populations and comparing the respective abundance trends from 1970 to present, Jellesmark *et al*. (in press) found that population trends of targeted vertebrate populations have been between 81% and 233% higher than their respective control population, whose trends are an unbiased estimator of the expected trends in absence of conservation efforts. They also found that a wide range of types of interventions were needed and differed in relative importance across species groups. The most prevalent interventions were habitat protection and land/water management, and species management actions were the main drivers of these recoveries or slower declines than the respective control populations. This study demonstrates that the actions needed to improve the status of these species are quite different from those needed for species on the verge of extinction.

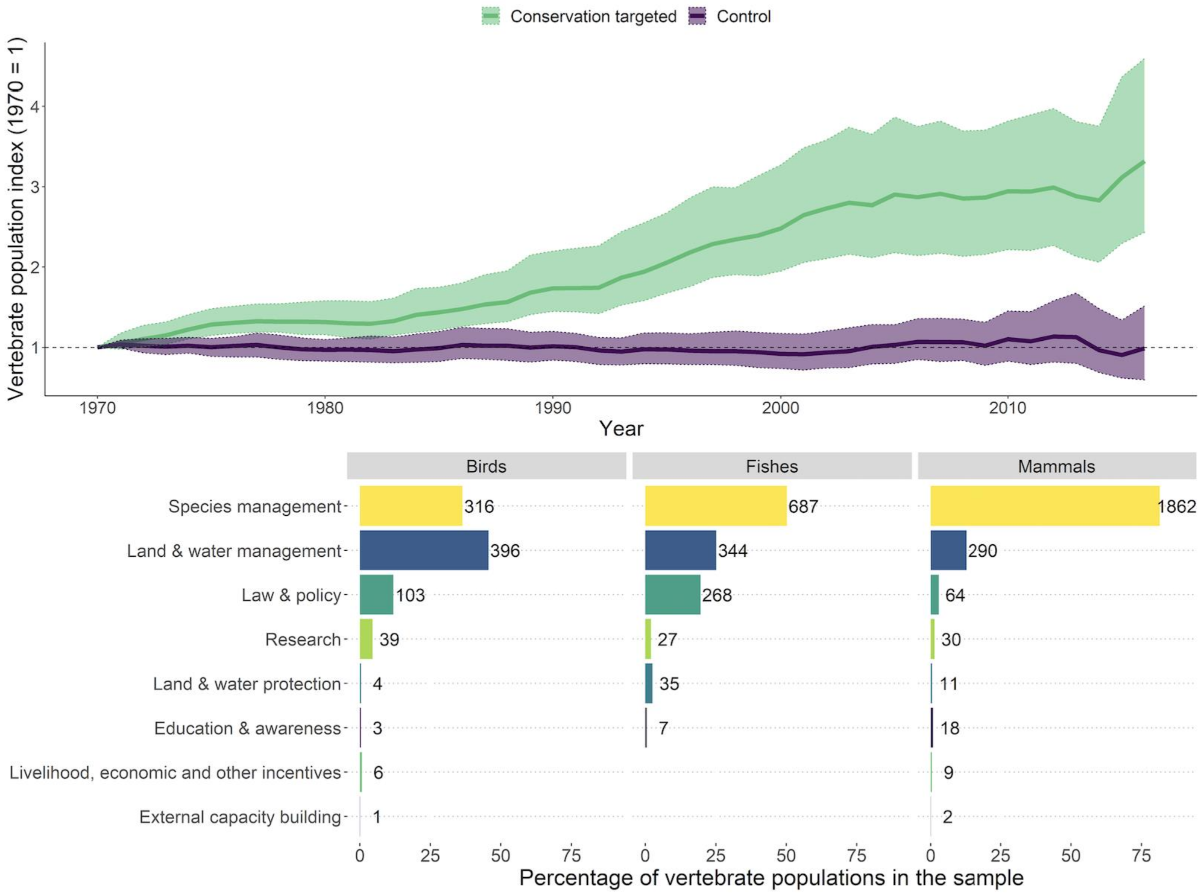


Figure 1.9 *Analysis of the benefits of conservation measures on vertebrate populations. Top panel: Vertebrate abundance trends for species subject to conservation actions (in green) and not targeted by conservation responses (in purple) over the period 1970-2020. Shaded areas show 95% confidence intervals. The sample of conservation targeted species includes 1,483 populations of 348 species, each matched to one or more control populations. Bottom panel: Number of targeted populations and the relative percentage of conservation actions for fish, birds and mammals. For each of the three groups with targeted conservation actions, the x-axis shows the percentage of populations targeted by the seven primary conservation actions and research.* (Source*: Jellesmark* et al*. in press).*

1.3.6 Scenarios and models of the future combined with an understanding of current trends indicate that transformative change is needed given the scale of changes in direct and indirect drivers required to achieve ambitious 2030 Milestones for biodiversity and the 2050 Vision. High levels of ambition for traditional conservation measures and restoration are necessary, but not nearly sufficient conditions for achievement of Goal A, as well as the Goals B and C which depend heavily on meeting Goal A.

This finding focuses on what can be learned from global scale scenarios and models, with an emphasis on analyses in the IPBES Global Assessment (IPBES 2019) and work that has been published since then (see also SCBD 2020). Scenarios and models have important limitations including that i) no global, regional or local scenarios treat the full set of drivers of biodiversity loss, ii) few studies cover more than one dimension of biodiversity and none cover all of the dimensions of biodiversity relevant to the GBF and iii) none precisely match the GBF targets, goals and milestones as they are currently worded. As such, there is a need to combine observations and scenarios to tell a coherent story about the future. In the future, more multi-sectoral scenarios will become available to better address synergies, trade-offs and other interactions across sectors.

<u>1.3.6.1</u> Scenarios on land for the period 2030-2050 show:

- Continued trends in direct and indirect drivers result in rapid degradation of all dimensions of biodiversity (although genetic diversity is rarely addressed).
- Strong conservation actions, including protected areas, can play a very important role in reducing biodiversity loss. However, protected areas with weak levels of protection, weak management or placement in areas of low biodiversity value are of little, or no, help in slowing biodiversity loss.
- Expansion of protected areas to 50% of land ("half Earth") may substantially increase the risk of food insecurity.
- Limiting global warming to 1.5°C or below is essential to meeting ambitious biodiversity goals, especially for 2050 and beyond.
- Conservation and restoration can slow biodiversity loss, but only transformative changes of underlying drivers such as unsustainable production and consumption can halt and reverse biodiversity loss over the long term.

<u>1.3.6.1.1</u> Scenarios, models and observations indicate that expansion of protected areas in the future could help slow biodiversity loss, but not halt it, and are only beneficial when properly placed and well-managed. Observations show that species abundance within protected areas has continued to decline, the placement and resourcing of the majority of protected areas has been poor, and more than half of recent protected areas have had significant increases in threats to biodiversity (Visconti *et al.* 2019; Bhola *et al.* 2021). Scenarios and models suggest that substantial increases in protected areas on land could be beneficial for biodiversity (see Box 1.2,

Table 1.3), but most of these scenarios assume that protected areas in the future are well-managed, well-placed and properly resourced. Scenarios with non-optimal placement, or weak management indicate that increasing protected area coverage will be of little value and even counter-productive (Nicholson *et al.* 2012; Visconti *et al.* 2019; Woodley *et al.* 2019). Scenarios and models also suggest that expansion to 50% global coverage of land area could compete for land with agriculture and substantially increase the risk for food security, especially in sub-Saharan Africa (see Box 1.2, Table 1.3).

<u>1.3.6.1.2</u> The global scenarios and models of terrestrial biodiversity developed in support of the IPBES Global Assessment (BES-SIM, IPBES 2019) provide a clear example of both the magnitude and levels of uncertainty involved in projected impacts of climate change on biodiversity. In this exercise, multiple models were used to explore the impacts of land use and climate on biodiversity (Figure 1.10). As in Leclère *et al.* (2020), the use of multiple models provided several indicators of biodiversity and allowed estimates of uncertainty in future projections. The most optimistic "Sustainability" scenarios included low climate change (RCP 2.6 ≈ likely less than 2°C warming), strong environmental governance and protection of existing natural forests (SSP1). In this scenario, the land use impacts on biodiversity indicators were small or reversed by 2050. However, when accounting for climate change and land use, climate change impacts greatly outweighed the land use impacts by 2050 and these climate change impacts resulted in projected large losses of biodiversity for all indicators even with only about 2°C of warming (SSP1-RCP2.6 scenario). However, models differed greatly in their sensitivity. Kok *et al.* (2020) found that the extinction risk is projected to rise at 2.1°C even with very substantial reductions in other pressures (in this case, much stronger measures than in the IPBES 2019 scenarios) but could be stabilized with global warming of 1.6°C (see Box 1.2, Table 1.3).

<u>1.3.6.1.3</u> The IPBES Global Assessment (2019) and Leclère *et al.* (2020) led the way in examining biodiversity change in scenarios designed to explore futures that resemble the 2050 Vision of the CBD, coupled with multiple models of biodiversity impacts. The GBO 5 (SCBD 2020) relied heavily on Leclère *et al.* (2020) in its "Future Outlook", and the Leclère et al. (2020) study is also heavily cited for levels of ambition of goals, milestones and targets of the GBF. In Box 1.2, we provide a summary of the major conclusions of Leclère *et al* (2020), and supplement it with a synthesis of recent global scale modeling that provides similar types of assessments of strong actions to halt biodiversity loss by 2030 and restore biodiversity by 2050. In addition, we provide a numerical analysis of major global scenarios relevant to land use targets (Targets 1, 2, 3) in

Appendix 1.3. As noted above, all of these scenarios indicate that conservation and restoration can slow biodiversity loss, but only transformative changes of indirect drivers such as unsustainable production and consumption can halt and reverse biodiversity loss over the long-term.

An important caveat concerning these scenarios is that they do not consider invasive alien species, pollution from fertilizers, pesticides and light (see Appendix 1.6 for discussion of future light impacts on species), bushmeat hunting, and many other factors that will increase human impacts on biodiversity. In addition, only two studies take into account climate change impacts on biodiversity.

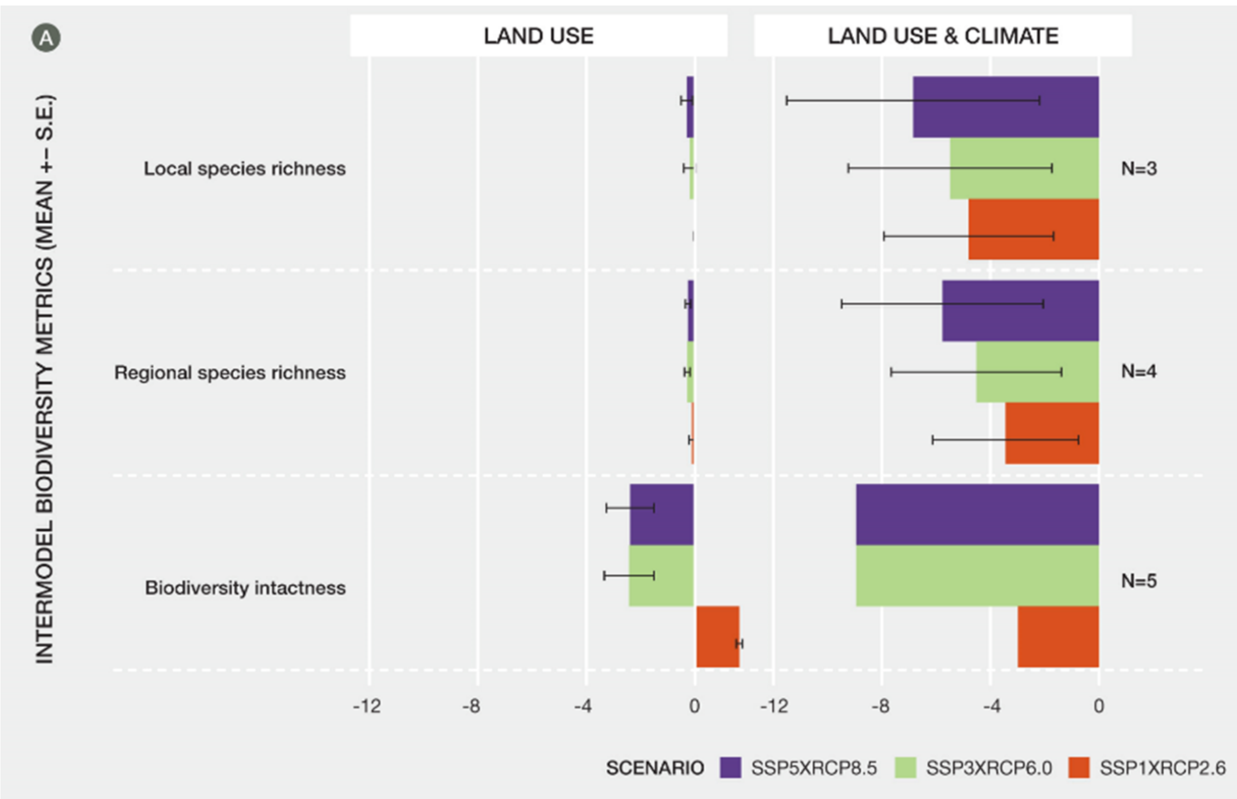


Figure 1.10 *Summary of relative changes in biodiversity metrics projected for 2015-2050 due to land use and climate change. Three future scenarios: green growth strategy with limited climate change (SSP1-RCP2.6); further fragmentation with high climate change (SSP3-RCP6.0) and fossil-fuel based economic development with very high climate change (SSP5-RCP8.5). Analyses were carried out for land use change impacts only (left panel) and land use change combined with climate change (right panel). Biodiversity metrics include changes in local species richness (= number of species in a small area), regional species richness (number of species at regional or global scales, the opposite of which is regional or global*

*extinction), and biodiversity intactness (i.e., abundance of plant and animal communities in disturbed compared to undisturbed, natural ecosystems). Values are averages of the outputs of the number of models indicated by N. Standard errors across models are indicated by whiskers when more than one model projection was available (*Source *Kim* et al. *2018, from IPBES 2019, Figure 4.2.1A).*

Box 1.2 *Lessons learned from global sustainability scenarios and models for terrestrial biodiversity.*

"Bending-the-curve" Scenarios (Leclère *et al.* 2020)

For terrestrial ecosystems, Leclère *et al.* (2020) mobilised a wide range of biodiversity models to examine plausible scenarios for halting the decline in several dimensions of terrestrial biodiversity by 2030 and restoring many by 2050 (also known as "bending the curve" for biodiversity; Figure 1.11). This study modeled the outcome of business-as-usual scenarios and compared it with various combinations of actions similar to Targets 1-4, 10 and 16 on several biodiversity outcomes (habitat extent, species population density, local compositional intactness and extinction risks) that can be linked to GBF Milestones A.1 (as proxies for ecosystem area and compositional intactness as one component of integrity) and A.2 (species populations density, extinction risk). Their analyses suggest it may be biologically plausible to halt the decline of most dimensions of biodiversity by 2030 and "bend the curve" by 2050 (with the important caveat that this work did not account for climate change impacts – see below). Achieving this however, will require successful implementation of all actions across traditional conservation measures, restoration and sustainable use and consumption. Without the full set of actions addressing all major indirect and direct drivers, the GBF targets will not be achieved. Importantly, addressing a wide range of drivers together typically makes it easier to address each one of the drivers. This is fully coherent with the findings of the IPBES Global Assessment (IPBES 2019).

The measures for conservation and restoration used in Leclère *et al.* (2020) can be considered roughly comparable in scope to the Targets 1-4 in the GBF, and assumes these targets are fully implemented. Taken together, these actions are projected to contribute substantially to achieving a global net gain in the area of ecosystems by 2030 (area component of Milestone A.1), and a stabilization (but not reversal) of species distribution, population and extinction rate (so making progress towards but not fully attaining Milestone A.2 objectives of early "bending-the-curve"; Figure 1.3). Time lags involved in biodiversity recovery (see Message 2 and Technical Section 2) reduce the likelihood of achieving ambitious outcomes for species and ecosystem integrity (as compared to ecosystem area outcomes) in 2030 milestones A.1 and A.2 and parts of the 2050 Goal A (implying strong recovery, beyond ecosystem extent). Future land use pressures, in particular the ongoing conversion of natural ecosystems in tropical areas, implies that despite conservation and restoration efforts (of an ambition similar to that in current GBF Targets 1-4, or higher), Goal A and milestones A.1-A.2 cannot be achieved, and especially increases in integrity. This is particularly true because ecosystem restoration cannot fully compensate for integrity losses due to conversion of natural ecosystems, especially when strict conditions for compensation are not respected (Díaz *et al.* 2020).

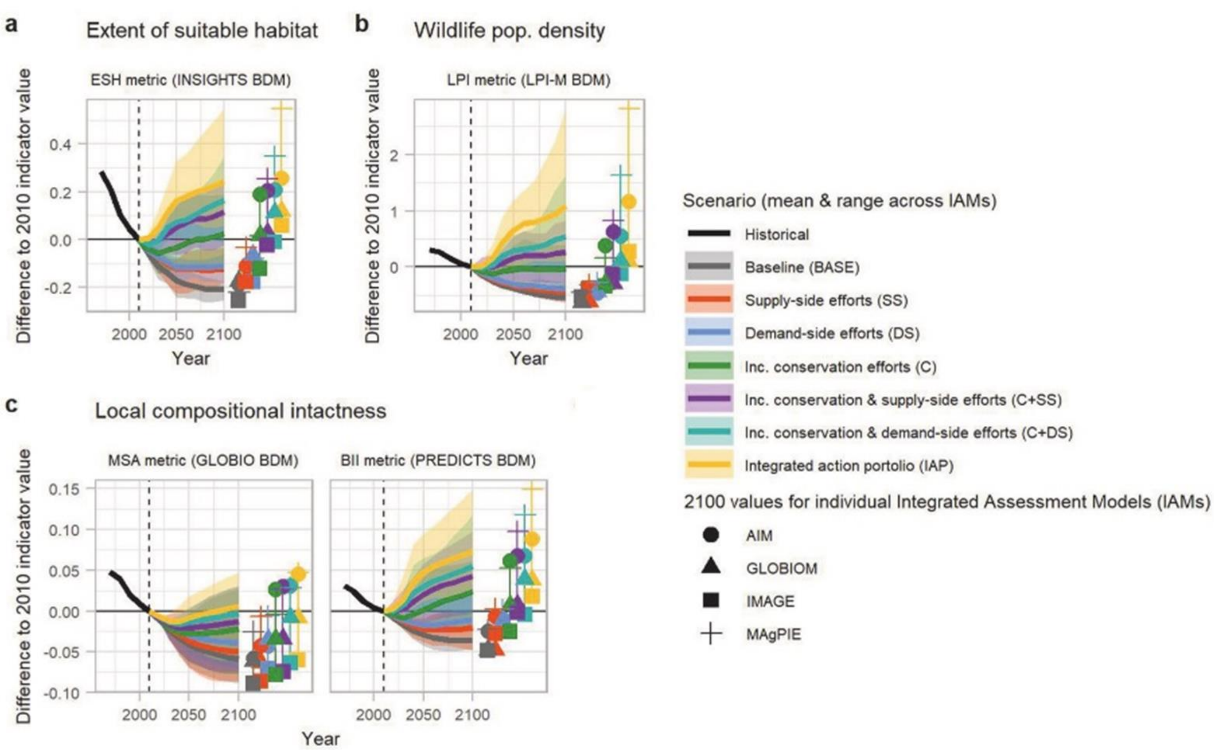


Figure 1.11 *"Bending the curve" projections from Leclère et al. (2020). BASE = baseline, SS = supply-side measures such as sustainable intensification of agriculture and trade, DS = demand-side measures such as reduced waste and diet shifts to avoid overconsumption of calories and meat, C = conservation and restoration efforts such as increased protected and restoration area and land use planning, IAP = integrated action portfolio [= C + SS + DS] for 4 land use models. Indicators include a) area of natural and semi-natural habitat, b) abundance of wild species and c) biodiversity intactness (Source: Leclère* et al. *2020, Figure 2a).*

More ambitious outcomes for biodiversity are not achievable without actions to tackle sustainable production and consumption. Such a scenario is not only needed to secure GBF's Goal A and milestones A1-2, but is also expected to contribute to the reduction of threats to biodiversity other than land use conversion (e.g., nutrient pollution and water abstraction from agriculture, net greenhouse emissions from land) and better alignment with the sustainable development agenda (including environmental goals, hunger and health).

Synthesis of recent global scale sustainability scenarios

Table 1.3 provides a qualitative synthesis of six very recent scenario studies that are relevant to setting ambition for the GBF goals, milestones and targets for terrestrial biodiversity (see also Appendix 1.3 for a quantitative analysis of the land use impacts on species extinction risk). We compare four scenarios that have a basis in the relatively complex Shared Socio-economic Pathways developed in support of the IPCC. Three of these, Leclère *et al*. (2020), Kok *et al.* (2020) and Soergel (*et al.* 2021), have made significant modifications to increase the representation of sustainability and explicitly add biodiversity conservation. Two of the scenarios (Williams *et al.* 2021 and Fastré *et al.* 2021) use statistical extrapolations of land use trends along with relatively simple assumptions about the land use implications of protected areas and food systems. These scenarios highlight the importance of i) well-implemented conservation and restoration and ii) transformations of agricultural production, sustainable diets and reducing food waste. Only two of the studies include climate change impacts on biodiversity (IPBES 2019; Kok *et al.* 2020) and both indicate that even low levels of climate change greatly increase the risks for biodiversity.

Regional scale implications

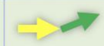
At regional scales, Williams *et al.* (2021) and Leclère *et al.* (2020) also point to the regional diversity of what constitutes the most efficient combinations of actions on direct and indirect drivers, and spillovers across regions via trade. Direct actions to stop habitat loss in one region are ineffective if the harmful activities relocate to another region as many of these activities are tightly linked to international value chains (Hoang & Kanemoto 2021). Direct actions to stop habitat loss are, thus, best complemented with action to replace these commodities by lower footprint alternatives to decrease the overall pressures, and thus decrease the risk of spillovers across regions.

Sustainability scenarios and models for terrestrial systems at local scales show that a combination of careful spatial planning, the introduction of sustainable or regenerative production practices and a decrease of overall pressure through the value chain (in sustainable consumption scenarios) are able to accommodate conservation and restoration practices that are in line with the GBF targets. Without addressing the indirect drivers that lead to pressures on the land system, it is often not possible to properly implement conservation and restoration actions, as displacement of activities within and beyond the region is a high risk (IPBES 2019). The IPBES Global Assessment also highlighted the importance of context dependency of sustainability pathways across regions (IPBES 2019, Chapter 5).

Table 1.3 *Analysis of six global sustainability scenarios. The four studies at the top of the table are based on modifications of the Shared Socio-economic Pathways (SSP) scenarios developed in support of the Intergovernmental Panel on Climate Change (IPCC). Background color: continued trends = grey, conservation and restoration only = blue, transformative change = green. Arrows indicate the qualitative response of biodiversity for habitat area, biodiversity intactness and extinction risk (downward arrows indicate more species threatened with extinction). Short arrows indicate responses for "current" to 2030 (first arrow) and then 2030 to 2050 (second arrow). Long arrows indicate responses for "current" to 2050. Color and angle of arrow indicate direction of response compared to reference date which is 2010 or 2015 for the long arrows and first short arrow, 2030 for second short arrow: black = very negative ; red = negative; orange = negative but slower than current trend; yellow = stabilization; green = slight improvement; blue = substantial improvement. In the "Scenario assumptions" column: SE = socio-economic scenario; CC = climate change scenario and projected 2050 global warming.*

Box 1.2 *continues*

Box 1.2 continued

Study	Scenario name	Scenario assumptions	Protected Areas	Restoration	Food Systems	Climate impact	Habitat Area	Intactness	Extinction Risk	Comments
IPBES (2019), Kim et al. (2019) Biodiversity model = Multi-model	Continued trends	SE = SSP3 CC = RCP6.0 ≈ 3-4°C by 2100	None explicit	None explicit	Continued trends	no				
	Continued trends	SE = SSP3 CC = RCP6.0 ≈ 3-4°C by 2100	None explicit	None explicit	Continued trends	yes				
	Sustainability	SE = SSP1 CC = RCP 2.6 ≈ 2°C, stable	30%, reduced deforestation	Not explicit	Close yield gaps Sustainable consumption	no				Weaker land use constraints than other sustainability scenarios
	Sustainability	SE = SSP1 CC = RCP 2.6 ≈ 2°C, stable	30%, reduced deforestation	Not explicit	Close yield gaps Sustainable consumption	yes				idem
Leclere et al. (2020)	Continued trends	SE = SSP2 CC = NA	no further expansion beyond 2010	None explicit	Continued trends	no				
Biodiversity model = Multi-model	Conservation and restoration	SE = SSP2 CC = NA	40% by 2020 (KBAs & Wild. areas)	≈5 million km² by 2050 (≈ 4%)	Continued trends	no				Also includes land-use planning over all land
	+ Sustainable production & consumption	SE = SSP1 CC = NA	40% by 2020 (KBAs & Wild. areas)	≈10 million km² by 2050 (≈ 8%)	Close yield gaps; Healthy diet, -50% meat; -50% food waste	no				Also includes land-use planning over all land
Kok et al. (2021)	Continued trends	SE = SSP2 CC ≈ 2,1°C rising	17% by 2020, no further expansion	None explicit	Continued trends	yes				
Biodiversity model = GLOBIO	Conservation = "Sharing the Planet Earth"	SE = SSP2 CC = 2,1°C rising	30% by 2050, focus ES	Rehabilitation	Continued trends	yes				
	Conservation ="Half Earth"	SE= SSP2 CC = 2,1°C rising	50% by 2050, focus BD	Ecological restoration	Continued trends	yes				Food security risk above SSP-2 baseline; highest food security risk
	Conservation = "Sharing the Planet" + Sustainability	SE = SSP2 CC = 1.6°C stable	30% by 2050, focus ES	Rehabilitation	Close yield gaps; Sustian diet, -50% animal products; -50% food waste	yes				Lowest food security risk Largest improvement regulating services

Study	Scenario name	Scenario assumptions	Protected Areas	Restoration	Food Systems	Climate impact	Habitat Area	Intactness	Extinction Risk	Comments
Soergel et al. (2021)	Continued trends	SE = SSP2 CC = NDC ≈ ??°C	None explicit	None explicit	Continued trends	no	↘↘	↘↘	—	Nat. habitat = primary and secondary vegetation?
Biodiversity model = BII	Sustainability + Climate mitigation	SE = SSP1 CC ≈ <1.5°C	Increase in forest protection	?	Close yield gaps Global equity	no	→→	→→	—	
	+ SDG package	+ try to meet all SDG objectives CC ≈ <1.5°C	Above + expansion to biodiversity hotspots	?	Close yield gaps Sustain. diets (EAT) Reduce food waste Global equity	no	↗↗	↗↗	—	Actions have strong synergies across multiple SDG goals. Lower food security risk
Fastré et al. (2021)	30% Strict Protected Area	SE = PA optimization CC - none	34% by 2030	19 million km²	Continued trends	no	→	—	↘	Arrows use 2015 baseline.
Biodiversity model = habitat suitability	100% Spatial planning	SE = land use optimization CC - none	17% + Spatial planning	14.5 million km²	Continued trends	no	↗	—	↗	Lowest trade-off between biodiversity and food security
	30% Strict PA + spatial planning everywhere else	SE = both of above CC - none	34% by 2030	18 million km²	Continued trends	no	↗	—	↗	Highest food security risk
Williams et al. (2021)	Continued trends	SE = Statistical extrapolation of land use trends	Continued trends	Continued trends	Continued trends	No	↘	—	↘	
Biodiversity model = habitat suitability	Spatial planning	SE = Global land use planning	Protect high priority areas	Not explicit	Continued trends	No	↘	—	↘	
	+ Sustainable production and consumption	SE = above + Sustainable agriculture and consumption	idem	Regrowth on abandonned land	Close yield gaps Sustain. diets Reduce food waste	No	↗	—	→	

1.3.6.2 Scenarios and models for oceans emphasize the importance of transforming fishing practices and limiting climate change to 1.5°C for protecting marine biodiversity. The IPBES Global Assessment (IPBES 2019) indicated that direct exploitation, and in particular fishing, has had the largest impact on marine ecosystems, but that climate change is projected to become an increasingly important direct driver. Recent large-scale scenarios and models of marine ecosystems support this growing impact. For example, Tittensor *et al.* (2021) applied ensemble models to show that, at a global scale, marine ecosystems are likely to face major biomass losses from climate change even in the absence of direct exploitation, although there remains uncertainty around trends at finer scales. These changes in underlying biomass are likely to have impacts on the total 'biomass potential' available to fisheries, although further scenario development is needed to project global-scale redistributions of fishing effort (and market demand) that respond to changing biomass patterns and climate change redistributions. Importantly, mitigation has a profound impact on reducing (though not eliminating) global marine biomass losses. Furthermore, nations with reduced socio-economic status in aspects such as ocean health, nutrition and wealth are likely to disproportionately experience the greatest impacts, yet mitigation would be of particular benefit to states in Asia, Africa and South America (Boyce *et al.* 2020).

Evidence also continues to accrue that biodiversity will be depressed in tropical marine regions as the climate warms and marine species shift (e.g., Yasuhara *et al.* 2020; Chaudhary *et al.* 2021), complementing prior studies that indicate that redistributions of biodiversity are likely to similarly redistribute fisheries catch potential, with drops in the tropics and increases in high-latitude regions (Cheung *et al.* 2010). The multiplicity of climate change impacts presents a risk to fisheries and fisheries management in terms of reference points (Travers-Trolet *et al.* 2020), may challenge the effectiveness of marine protected areas (Tittensor *et al.* 2019), and will open up Arctic regions to new fisheries with the potential for resource conflicts. Beyond these broad fisheries and biodiversity consequences, the multiplicity of climate impacts includes increased coral bleaching (McWhorter *et al.* 2021), expansions of low oxygen areas in the ocean, the range of impacts of increased ocean acidification and more.

These climate impacts are set against a background of changing demographics and an increasing human population that are projected to drive a near doubling in global fish demand by 2050. This demand will be satisfied by a combination of wild capture fisheries and (freshwater and marine) aquaculture, with consequences for biodiversity contingent on the relative proportion, and sustainably, of these components. Effective governance and enforcement, together with considerations of equity and the role of small-scale fisheries and aquaculture (Short *et al.* 2021), are likely to play an important role in building sustainable oceans, as are considerations about blue carbon and the role of the oceans in climate change mitigation. While a broad spectrum of other impacts plays a role in terms of future biodiversity (e.g., pollution, marine noise, deep-sea mining), these tend to be less well-explored in terms of large-scale scenarios, and quantitative models of climate and fisheries impacts generally do not include these aspects (though some hybrid smaller-scale models are more integrated, e.g., ATLANTIS).

Large-scale quantitative scenario studies of the future impacts of exploitation and fishing pressure on biodiversity and ecosystems remain relatively limited, in part because of the challenges of developing bio-economic models to evaluate the dynamic redistribution of fishing effort as the environment, regulatory effectiveness, spatial closures, market demand and target species change over time. Thus, studies tend to evaluate economic benefits and impacts on target stocks, rather than biodiversity and ecosystems *per se* (e.g., White & Costello 2014; Sumaila *et al*. 2015), or catch potential, i.e., maximum catch given underlying potential biomass (e.g., Cheung *et al.* 2016), rather than two-way dynamic impacts and interactions between biodiversity/ecosystems and the fisheries it supports. However, recent analyses have started to more fully couple climate-exploitation-economic-biodiversity models to explore impacts of marine high temperatures, and highlight the benefit of climate-sensitive fisheries management (Cheung *et al.* 2021). An important consideration in terms of the milestones for 2030 and goals for 2050 in marine systems, is that recovery rates across several commercially fished marine species show that recovery of the biodiversity and function of marine systems could be achieved by 2050, if major pressures, including climate change and fishing pressure, are mitigated (Duarte *et al.* 2020; see also Section 2).

<u>1.3.6.4</u> Scenarios and models for freshwater systems emphasize the importance of restoring water flow and water quality as a key to reversing biodiversity loss in streams, rivers and lakes. Tickner *et al.* (2020) summarised six actions for bending the curve in freshwater biodiversity decline beyond 2020: accelerate the implementation of environmental flows, improve water quality, protect and restore critical habitats, manage the exploitation of species and riverine aggregates, prevent and control invasive alien species and safeguard freshwater connectivity. The fragmentation of free-flowing rivers is rated the biggest threat for freshwater megafauna, which is declining by >85% (He *et al.* 2019; van Rees *et al.* 2021). A critical part of conserving and managing freshwater ecosystems post-2020 is the recommendation for connectivity across

multiple spatio-temporal scales and hydrological dimensions.

Freshwater ecosystems also need to be considered within the context of their waterscapes or catchments, i.e., drainage networks, catchment areas and bordering ecotones, as they do not function in isolation from their terrestrial and atmospheric counterparts. The identification and adoption of flagship umbrella species may help raise awareness and funding, e.g., sturgeons (Acipenseridae) in the Danube River or the red-crowned crane (*Grus japonensis*) in Japan (Kalinkat *et al.* 2017). A global evidence base for invasive alien species impacts based on indicators such as the International Union for Conservation of Nature Environmental Impact Classification for Alien Taxa framework (IUCN EICAT; Blackburn *et al.* 2014) and future scenarios (Roura-Pascual *et al.* 2021) are critical for assessing the ecological status of freshwater ecosystems. Future policies should support research and management that enhance the interactions between integrated water resources management and ecological integrity for freshwater biodiversity conservation.

New strategies and available decision-support tools to navigate the complexity of freshwater ecosystems and societal demands can inform and enhance decision-making at the catchment scale, help handle trade-offs and foster support through community inclusion. Strategic planning methods will benefit from inter- and trans-disciplinary research and clear objectives in which the multiplicity of interests is accounted for (van Rees *et al.* 2021, recommendation #14). Maasri *et al.* (2021) highlight knowledge gaps, miscommunication among scientists, practitioners, managers and policymakers, and inadequate policies as the main challenges in advancing biodiversity research in freshwater ecosystems. They recommend strengthening research efforts, enhancing science-based strategies and methods for sustainable freshwater biodiversity management, and designing conservation strategies that account for the societal responses to biodiversity change. They also stress the importance of considering the social, cultural and economic context of protecting and recovering freshwater biodiversity.

1.3.7 The various dimensions of biodiversity differ in the relative importance of direct drivers, actions required to reduce threats, tools for implementation, lags in response to changes in drivers and requirements for indicators and monitoring. Accounting for these differences among dimensions could bring greater clarity to the formulation of ambition and quantitative elements of the goals, milestones and targets of the GBF and help in the translation of these global targets to national and local action plans.

1.3.7.1 The GBF breaks down biodiversity objectives in Goal A into three dimensions of biodiversity and seven components of change: ecosystems (area, connectivity and integrity); species (extinction rate, extinction risk, abundance and distribution); and genetic diversity (diversity). To illustrate how these components differ in the relative importance of drivers and actions and drivers we have analysed area and integrity of natural ecosystems (Milestones A.1 and A.3, sub-section 1.3.7.4-6) and species extinction rate and extinction risk (Milestones A.5 and A.6, sub-section 1.3.7.7-9). We have not treated the other components of Goal A (ecosystem connectivity, species abundance and distribution and genetic diversity) due to lack of time. They are clearly as important as the components we have analysed and would benefit from a similar type of analysis to support the discussions of the GBF.

1.3.7.2 The take-home messages from these analyses are that i) numerical objectives are likely to differ across the various components of biodiversity in Goal A and ii) global targets provide an important template for action, but it is the specifics of implementation that will determine whether actions will be successful or not.

1.3.7.3 Managed ecosystems are not well addressed in the current state of the GBF (see Section 5). Nearly 40% of the world's ice-free surface is currently allocated to food production (agricultural and rangelands), with another 10% approximately classified as urban. These "working lands" should not be exempt from transformative changes. Because of their proximity to human populations, they are the areas that account for a majority of locally provided contributions to people. The integration of biodiversity to secure or regenerate ecological function in these areas is underserved in the GBF goals and targets. With better integration, working lands can become sources of important NCP's, and contribute to increasing connectivity between intact ecosystems.

1.3.7.4 Area and Integrity of Natural Ecosystems - Goals and Milestones
Current language in Goal A and Milestone A.1 in terms of "net" changes in ecosystem area and integrity poses serious risks of failing to halt the destruction and degradation of critical ecosystems (Díaz *et al.* 2020). This risk can be addressed by:

> Adding language on "strict conditions and limits to compensation, including 'like-for-like' (substitution by the same or similar ecosystem as that lost) and no loss of 'critical' ecosystems that are rare, vulnerable, or essential for planetary function, or which cannot

be restored" (Díaz *et al.* 2020; Maron *et al.* 2021).

Separating language on natural ecosystem destruction and degradation from language on restoration, in line with the Glasgow agreement. For example, for Milestone A.1:

> *"A) Loss in area and integrity of all natural ecosystems is [reduced by xx% or halted] starting in 2022 (see also pledge on halting forest loss signed at Glasgow during UNFCCC COP26)*
> *B) By 2030, restoration actions are established/implemented to reverse loss in area and integrity in all natural ecosystems"* (Nicholson *et al.* 2021).

In this formulation, note that halting natural ecosystem destruction and degradation is not considered to be feasible starting in 2022, and that this could either refer to halting net loss or reducing conversion of natural ecosystems by xx%.

A "no net loss" or "net gain" formulation explicitly permits loss of ecosystem area through compensating for loss by restoration. Without strict conditions, this is likely to result in net loss in area in the short-term (e.g., when do freshly planted trees or re-flooded wetlands count as an increase in area of a "natural" ecosystem?). Importantly, it will inevitably lead to absolute and net loss in integrity in both the short and long-term. Time lags mean that newly restored areas take decades to become functioning ecosystems (Jones *et al.* 2018; Duarte *et al.* 2020; Poorter *et al.* 2021) and may never fully recover species composition (Section 2; Crouzeilles *et al.* 2016; Watts *et al.* 2020), nor reach levels of integrity (measured by composition and function) of original intact areas. Changes in ecosystem integrity are also difficult to monitor, and are therefore likely to go unobserved, giving a false sense of security of the success of the GBF. Measuring ecosystem integrity is one of the weakest areas within the monitoring framework (Sections 4 and 5); many of the proposed integrity indicators rely on land use change (i.e., complete conversion from one ecosystem type to another), rather than degradation of ecosystem characteristics, and a lack of data at appropriate spatial and temporal scales hinders effective ecosystem-specific monitoring of integrity (Nicholson *et al.* 2021).

Insufficient attention has been paid in the GBF to the role that climate change will play in meeting ambitious ecosystem targets (Arneth *et al.* 2020). Climate change is not currently one of the most important drivers of changes in the ecosystem area, but large-scale regime shifts caused by climate change could make it a major driver by 2050. Climate change is already an important driver of change in ecosystem integrity, and all models suggest it will become a primary driver of degradation of ecosystem integrity by 2050 even if ambitious climate mitigation and adaptation targets are met. The actions proposed are likely to be insufficient to reach the goals when accounting for climate change. Perhaps most importantly, ecosystems in the future will be different than they are now, so this should be taken into account when devising and evaluating indicators for ecosystem integrity.

Avoiding ecosystem tipping points would be an important additional objective and was embodied in early versions of the GBF in language about maintaining and enhancing ecosystem "resilience" in terms of both ecosystem function and biodiversity. A number of formulations have been proposed that would not substantially add to the complexity of Goal A and Milestone A.1 (e.g., Nicholson *et al.* 2021). Preventing ecosystem tipping points is akin to preventing species extinctions: both aim to halt the loss of fundamental dimensions or units of biodiversity, which is embedded in the 2050 Vision.

<u>1.3.7.5</u> Area and Integrity of Natural Ecosystems - Need for concerted actions

Reducing and halting loss of ecosystem area requires strong area-based actions (Targets 1 and 3), which are conditional in their effectiveness by strong actions on indirect drivers of ecosystem conversion especially consumption, production and trade (Targets 10, 14-18).

Degradation of ecosystem integrity is often caused by multiple, interacting direct and indirect drivers and the relative importance of these drivers varies greatly across ecosystems. Thus, strong action on all drivers is required to meet ambitious ecosystem integrity goals. Diagnosis of these interactions is needed to understand how actions can work synergistically to halt declines or enhance ecosystem integrity; this requires causal theories of change or conceptual model (Burgass *et al.* 2021).

<u>1.3.7.6</u> Area and Integrity of Natural Ecosystems - Levels of ambition for selected targets

The efficiency and efficacy/effectiveness of protected areas (PAs) in safeguarding species and ecosystems are strongly dependent on the locations chosen. If not optimally allocated and coordinated, a larger extent of PAs is needed to reach the targets. The siting and efficacy of area-based measures are more important for avoiding the loss of critical ecosystems and for ensuring coverage of all ecoregions than global scale PA coverage. As it is unlikely that PA coverage will be optimally allocated, or that efficacy will be high for all ecosystems, spatial planning (Target 1) to avoid destruction of natural ecosystems outside of PAs is essential. This is coherent with the current wording of implementing spatial planning for all terrestrial ecosystems. Such spatial planning needs to go hand-in-hand with sufficient measures to avoid loss or degradation of natural ecosystems outside PA networks.

Protected areas are a legal status related to, but independent of biological definitions of areas of intact nature, or ecosystem integrity. Many PAs target specific dimensions of biodiversity. Evidence suggests that currently, between 45-60% of the Earth's ice-free surface is "intact" even when occupied or used by humans (e.g., many indigenous areas). Halting the conversion and loss of these areas, as articulated in Target 1 is an important complement to protection.

While protected areas and other areas of effective area-based conservation measures (OECMs) may halt some direct drivers (e.g., land use change or direct exploitation), effective and equitable management and implementation will be needed or risk being paper parks. Other drivers will require active management, such as active species recovery (Target 4), invasive alien species (Target 6) or pollution (Target 7), where PAs support or provide funding mechanisms for the implementation of other action targets.

Current levels of ambition for targets for invasive alien species and pollution are insufficient to achieve net increases in integrity, or even to halt loss of integrity. They aim to reduce the establishment of invasive alien species and pollutants discharged into the environment. This implies continued degradation of natural ecosystems.

There is no explicit target for active management of ecosystems to retain as well as recover integrity (comparable to Target 4 for species). Many ecosystems require ongoing management to retain integrity and ecosystem processes (e.g., Regan *et al*. 2011), particularly where natural processes such as pollination or dispersal, fire or flood regimes, may have been lost or altered due to fragmentation of land-use in surrounding areas or local extinctions of key species; such ecosystems may also be of high conservation importance (e.g., highly threatened or supporting threatened species) and embedded within anthropogenic landscapes (Wintle *et al.* 2019).

Securing good governance of the area and integrity of natural areas outside of PAs and OECMs is critical. Spatial planning is important, but instruments need to be in place to safeguard those areas, such as strong environmental legislation to address land clearance and habitat loss, especially in critical ecosystems and threatened species habitat (e.g., Alaniz *et al.* 2019; Bland *et al.* 2019). For example, in Australia, >65% of native forest is held on private lands (ABARES 2018); halting loss of these forests, the species they sustain and the NCPs they support (Goal B), is dependent on effective regulation and inclusive governance (e.g., Ullah & Kim 2021).

1.3.7.7 Species Extinction Rate and Extinction Risk - Goals and Milestones

Goal A has two interlinked components related to extinction: extinction rate (the speed at which species become extinct) and extinction risk (the likelihood that a species will become extinct in a given period of time). These two measures of extinction are interlinked but can require slightly different types of action. Reducing extinction risk across a large group of species is better achieved through area-based measures (including protected areas, restoration) and legislation (e.g., on species protection or restriction of species trade) that address direct drivers, or through other conventions/agreements that act on indirect drivers (e.g., promoting sustainable consumption, production and trade as well as climate mitigation; see Box 1.2). These actions will also participate in reducing extinction rate, which also requires direct action on individual species with a very high risk of extinction. This type of action includes re-introductions, assisted migration, and intensive management of depleted populations, and is typically expensive, and has proven effective in preventing recent extinctions (Bolam *et al.* 2021; Figure 1.8).

Several caveats should be kept in mind when evaluating the ambition and feasibility of extinction rate goals and milestones. It is difficult to measure extinction rates over short time periods (2022-2030), saving species with very small populations is difficult (e.g., low genetic diversity, susceptibility to catastrophic events), and the rising threat of climate change could make the number of species requiring extreme conservation measures (e.g., *ex-situ* conservation) far too large to handle (Urban 2015; IPCC 2019).

Overall, scenarios, models and observations suggest that it may be possible to reduce extinction rates over the next few decades, but that reaching zero extinctions across a wide range of species groups is not considered to be feasible (Box 1.2, Appendix 1.3 and Box 1.3 below, see also Díaz *et al.* 2020).

Box 1.3 *Extinction rates for several species groups.*

Birds and mammals - A substantial reduction in bird and mammal species extinctions over the coming decade is considered feasible with ambitious concerted action on direct and indirect drivers. Ten (of about 11,000 total) bird species and five (of about 5,600 total) mammal species are suspected of having gone extinct between 1993-2020 (IUCN 2021; Bolam *et al*. 2021). The drivers and actions required to avoid extinctions in species that are critically endangered are summarised in Box 1.2. Reducing extinctions with ambitious, concerted actions is considered feasible over the coming decades (Bolam *et al*. 2021; Williams *et al.* 2021).

Amphibians - There has been a decline in abundance of about 500 amphibian species over the past half-century, including 90 presumed extinctions out of a total of about 6,600 known species, many over the last few decades (Scheele *et al.* 2019). The primary driver of this loss is amphibian chytridiomycosis panzootic, compounded by habitat loss and degradation, pollution, other invasive alien species and climate change (Scheele *et al.* 2019). Important indirect drivers of the disease spread are trade and local human activities. Species management, protecting and restoring habitat and reducing pollution have helped reduce the risk of extinction, but there is a significant risk of substantial further amphibian extinctions over the next decades as the chytrid fungus continues to spread globally (Scheele *et al.* 2019).

Freshwater molluscs – A recent estimate of extinctions in freshwater molluscs suggests about 5% of species are extinct, 15% are critically endangered and 30% are threatened globally, driven primarily by pollution and habitat modification (Böhm *et al.* 2021). High endemicity contributes to the particularly high extinction rates for this species group. There are no credible estimates that extinction rates of invertebrates could be brought close to zero over the period 2022-2050.

Insects – Extinction rates for insects are extremely difficult to document due to large numbers of species and lack of data. Estimates of species numbers are very large: “one million described species of insects and even the most modest estimates calculate that another 4.5 to 7 million remain unnamed” (Wagner *et al.* 2021; see also Cardoso *et al.* 2020; Klink *et al.* 2020). One estimate of extinctions for all terrestrial invertebrates is over 100,000 species over the last century, although this has very high uncertainty (Régnier *et al.* 2015). Extinction rates in the future could rise rapidly because there have been very rapid, broad declines in insect populations in some regions, even for species that were abundant until very recently. Insects are suffering a “death by a thousand cuts”’ due to a combination of pesticide, herbicide, light and nitrogen pollution in human dominated systems, and habitat destruction (Wagner *et al.* 2021; see Appendix 1.6 on the growing problem of light pollution). There are no credible estimates that extinction rates of insects could be brought close to zero over the period 2022-2050.

1.3.7.8 Species Extinction Rate and Extinction Risk - Need for concerted actions

Avoiding extinctions for any single species usually requires multiple actions on indirect and direct drivers.

- Area and habitat-based measures play a critical role in most cases, but are largely insufficient by themselves.
- Actions vary greatly between species, species groups and regional contexts, so greatly reducing extinctions across all threatened species requires high ambition on all 21 Targets.

1.3.7.9 Species Extinction Rate and Extinction Risk - Levels of ambition for selected targets

The protection of 30% area is not estimated to cover the full range of species’ minimal population sizes, even if optimally allocated for species globally (Target 3); other area-based measures (e.g., Target 1 on spatial planning) are essential complements (Fastré *et al.* 2021; Jung *et al.* 2021; Plumptre *et al.* 2021). The siting and efficacy of area-based measures is much more important for avoiding extinctions than percent protected area coverage (see 1.3.6.1.1). In addition, because area-based measures do not fully insulate species from the pressures of pollution, IAS or climate change, even strict protection does not halt the decline of species abundance and increased threatened status in many cases.

Species management plans (Target 4) are key to avoiding extinctions in nearly all cases, but Target 4 has no quantitative elements (Visconti *et al.* 2019). Developing and implementing management plans to save species near extinction often require high levels of resources and therefore this would need to be reflected in Target 19. Species management plans also usually require addressing a wide range of indirect drivers embodied in Targets 10-21.

Unsustainable exploitation of wild species (Target 5) is a primary driver of extinctions in some species groups, such as mammals. This target does not have a quantitative element, but could be read to mean it refers to 100% of species. This could significantly contribute to reducing extinctions (with caveats). Target 10 states that all areas under forestry management are sustainable can also be read as meaning 100%. Both may benefit from clarification.

Invasive alien species and diseases (Target 6) are the primary driver of extinctions in many species groups, including small mammals, birds and amphibians. Large reductions in the establishment of new IAS populations by preventing their introduction and spread, and by eradicating particularly harmful invasive populations are important for avoiding extinctions in the longer-term. In addition, well resourced, ambitious actions to halt or mitigate the impacts of IAS now, especially through eradication of priority species, are essential for reducing extinctions by 2030. This would therefore need to be reflected in Target 19, and perhaps more strongly reflected in the wording of Target 6.

Pesticide, herbicide, light, nitrogen and phosphorus pollution (Target 7, see also Appendix 1.4) are the primary driver of species extinctions in many species groups, especially invertebrates. Substantial reductions in pollution are essential in many regions to reduce extinctions. The level of ambition for reductions in pollution depends more on achieving very low impacts of pollution on species and ecosystems, rather than percent reductions *per se*.

Climate adaptation plans will be essential and are addressed in Target 8, but there could also be explicit recognition that warming above 1.5°C will seriously compromise efforts to slow and halt extinctions.

Management plans that have saved species from extinction have often depended on ambitious legislation and enforcement. Actions that increase awareness, education and communication, engagement of local communities, capacity-building and actively involve the business and financial sector (for example, through innovative use of incentive structures and market tools) are essential (Targets 14-21).

Technical Section 2: Temporal Lags

2.1 High-level findings for the global biodiversity framework

2.1.1 There is good evidence that many dimensions of biodiversity, on land and in the oceans, will continue to decline to 2030 and beyond because of the pervasive and lasting effects of human-induced drivers. The sooner we reduce the impacts of drivers, the lower the cumulative loss of biodiversity and ecosystem processes experienced in the coming decades.

2.1.2 Ambitious action is needed immediately and must be binding and sustained if we are to put biodiversity on a trend to recovery by mid-century. Milestones for 2030 should be framed as intermediate objectives that account for biodiversity lags on the pathway to achieving the goals for 2050.

2.1.3 Responses of biodiversity to interacting drivers (e.g., between climate change and land and sea change) will involve long time lags. In this context, we do not always expect biodiversity to recover to a historically recognised ecosystem and biodiversity state.

2.1.4 Monitoring assisted by models and indicators can be used to assess progress despite lagged responses by different dimensions of biodiversity. This knowledge can be used to adjust actions for sustained recovery.

2.2 Plain-language summary

Biodiversity change

The biodiversity change occurring in a location can be thought of as a dynamic 'budget' composed of losses (e.g., species extinctions) and gains (e.g., species colonization, speciation) occurring over time (Jackson & Sax 2010). The processes causing extinction (or extirpation, if local) and colonization can be set in motion by human caused drivers that affect the quality, size, density, and connectivity of suitable habitats that maintain diversity. Net biodiversity loss arises from losses exceeding gains, with net biodiversity gains resulting from the opposite. Drivers alter the rates of gains and losses differently across distinct biodiversity dimensions (genetic, population, species diversity, etc.). For example, climate change is expected to drive increases in population extinction rates by creating mismatches in the timing of species interactions or the loss of population viability due to climate extremes raising mortality and eroding genetic diversity. Another example is when deforestation initiates extinctions by reducing population sizes, and isolating populations in remnant forest fragments. Current representations of human drivers underestimate the overall pressure on the biodiversity budget (Harfoot *et al.* 2021), and relatively few studies have assessed the effects of multiple interacting drivers (Mazor *et al.* 2018) such as the interaction between climate change and habitat loss.

Drivers act in different ways

Long-term trends characterizing biodiversity and ecosystem change depend on the action of direct and indirect drivers. Drivers can be rapid and punctuated (e.g., industrial deforestation, pollution events, fires outside fire prone habitats) or slow and gradual (e.g., urban sprawl, sea-level rise, chronic nutrient pollution, or secular temperature change), and singular (e.g., permanent deforestation, drainage or transition to a new climate regime) or sustained (e.g., forest to cropland and cropland to suburb) over time. Beyond the immediate and obvious responses (e.g., rapid loss of species or individuals, change in habitat size and quality) there are delayed and long-term changes in the biodiversity budget particularly after extreme events (Krauss *et al.* 2010; Hillebrand & Kunze 2020; Watts *et al.* 2020; Parkhurst *et al.* 2021).

Biodiversity time delays

The response of biodiversity to changing pressures from human drivers can occur immediately but change typically takes much longer (Krauss *et al.* 2010; Brotherton *et al.* 2019; Isbell *et al.* 2019; Trindade *et al.* 2020; Warner *et al.* 2021). Our accumulated knowledge now shows that biodiversity change in response to drivers, including both biodiversity declines and recovery can involve long delays (i.e., time lags) lasting years to millennia (Essl *et al.* 2015a; Figueiredo *et al.* 2019). These time delays can result from simple and complex causal effects of direct and indirect human drivers and differ in their length and magnitude (Table 2.1; Kuussaari *et al.* 2009; Figueiredo *et al.* 2019; Deák *et al.* 2021). For example, rapid habitat loss can erode population genetic diversity, impeding recovery for decades (or many generations for some organisms), and it can also trigger cascading effects on the food web and long-lasting shifts in ecosystem state. Biodiversity time lags, both in response to, and recovery from, drivers are known to occur in terrestrial, freshwater, and marine ecosystems (Jones & Schmitz 2009; Moreno-Mateos *et al.* 2017, see Appendix 2.1 Box 2.1, 2.2). These lasting biodiversity responses may also hinder recovery when effects of drivers are diminished or eliminated.

Biodiversity time lags differ in their duration and magnitude depending on the nature of the disturbance (Figure 2.1). Assessment of extinction risk may depend not only upon the current state of the landscape and its projected trajectory of change, but also on its past disturbance history. For example, an extinction debt is any future biodiversity loss that current or past habitat destruction or disturbance will incur but which has yet to be realised because of time delays in extinction (Tilman *et al.* 1994; Hanski & Ovaskainen 2002; Figueiredo *et al.* 2019). The extent of an extinction debt depends on the number of species close to their extinction threshold as an outcome of habitat loss and degradation and the degree of fragmentation and quality of the remaining habitat. The more fragmented and modified a habitat already is, the greater and faster is the number of extinctions caused by added destruction. An extinction debt can be curtailed, partially if not completely, if action is implemented to stop habitat loss and fragmentation and restore area and connectivity (Meyer 2019).

This strong time-dependence in ecological change means that biodiversity recovery (a return to a given reference state) may only occur many years after the onset of management action to cease the pressure from a driver. In some cases, recovery may take millenia (Davis *et al.* 2018). Differences in recovery rates and extent arise because losses, gains and turnover of distinct and interdependent dimensions of biodiversity (e.g., genetic, population growth, species composition) differ depending on the driver and the ecological and evolutionary processes involved.

Local communities, stakeholders, and indigenous knowledge can support recovery

While research mainly emphasises the negative impacts of people on biodiversity change, legacies of past indigenous land-use have been shown to maintain their positive effects on contemporary functional and taxonomic diversity long after the cessation of management (Armstrong *et al.* 2021). There are also several situations when centuries-long human activities contributed to recovery in the long term (Díaz *et al.* 2019; Eriksson 2021). Deforestation followed by a fine-tuned management created species-rich habitats and new ecosystems with high value in cultural landscapes (e.g., hay meadows, wood-pastures or tropical forest gardens; Díaz *et al.* 2019; Armstrong *et al.* 2021; Molnár & Babai 2021). When setting restoration goals, it is important to recognise the diverse motivations that influence them. In doing so, and by evaluating both social and ecological benefits, we can better achieve restoration outcomes (Jellinek *et al.* 2019).

Loss of biodiversity may continue during recovery

The loss of biodiversity and ecosystem functioning may occur during recovery causing what is called a recovery debt (Moreno-Mateos *et al.* 2017). A recovery debt is a shortfall in biodiversity and ecosystem functions that accumulate during the process of recovery (Figure 2.2). Moreno-Mateos *et al.* (2017) found that recovering and restored ecosystems have less abundance, diversity and cycling of carbon and nitrogen than 'undisturbed' ecosystems, and that even if complete recovery is reached, an interim recovery debt will accumulate in different dimensions of biodiversity (Figure 2.3). The science is in place to detect and monitor recovery debts using sensitive indicators (Dubois *et al.* 2019).

Appropriate baselines, reference systems and indicators are required to establish whether recovery has occurred (Westwood *et al.* 2014). In the context of historical and ongoing ecosystem degradation, baselines may shift, resulting in inappropriate targets for nature conservation, restoration, and management during recovery (Soga & Gaston 2018). Indigenous knowledge can provide a long-term perspective and correct a shifting baseline syndrome during efforts to recover biodiversity and ecosystem (Uprety *et al.* 2012; Mustonen 2013; Mistry & Berardi 2016; Jardine 2019). Local and traditional ecological knowledge is increasingly important given the widespread challenges of ecosystem degradation and climate change.

It is the mitigation of drivers and the recovery of the underlying processes that determine the time course of biodiversity and ecosystem recovery (Westwood *et al.* 2014). Time delayed responses of biodiversity must be accounted for when planning milestones for quantitative targets and goals, and when choosing appropriate measures for those targets.

Table 2.1 *The different causes and consequences of delayed biodiversity change, including examples and implications for management. Twelve mechanisms leading to delayed biodiversity responses are given* (Source: *Essl* et al*. 2015b*).

No	**Mechanisms**	**Examples**	**Relevant species attributes**	**Consequences**	**Implications for management**
1	Ecosystem loss (i.e., quantitative ecosystem change)	Forest clearing; conversion of grasslands to agricultural fields	Generation time; population dynamics; minimum viable population size	Delayed local population and/or species diversity decline and loss	Reserve planning and management; ecosystem conservation and restoration; long-term biodiversity monitoring
2	Ecosystem degradation (i.e., qualitative ecosystem change)	Input of nutrients; toxic substances; loss of ecosystem structures	Life-history traits that are relevant for the factor implicated in ecosystem degradation (e.g., sensitivity to toxic substances)	Delayed local population and/or species diversity decline and loss	Ecosystem management; long-term biodiversity monitoring
3	Changes to ecosystem connectivity	Increased fragmentation of ecosystem patches; increased connectivity (e.g., rivers connected by artificial waterways)	Dispersal capacity; (meta)population dynamics	Delayed increase in (meta)population extinction risk; delayed local population and/or species diversity decline and loss	Corridor planning; 'Green infrastructure'
4	Climate change	Range and abundance changes of species tracking climate change	Dispersal capacity; population dynamics	Delayed trailing and leading species range dynamics; delayed changes of species abundances	Monitoring of current and projections of future range and population dynamics; ecosystem-based adaptation

5	Changes in disturbance regime	Change in natural (e.g., fire, floods) and anthropogenic (e.g., traditional land-use) disturbance frequencies and intensities	Species ecology (e.g., serotinous species for changes in fire regime)	Delayed changes in species composition and ecosystem structures	Evaluate and integrate lagged biodiversity responses in the management of natural and anthropogenic disturbances
6	Changes in biotic interactions	Loss or establishment of biotic interactions (e.g., parasitic, symbiotic, or trophic)	Trophic position, species ecology	Delayed loss or establishment of biotic interactions; delayed reaction of indirectly affected species and/or trophic groups (e.g., pollinators as a consequence of a decline of plant species richness due to ecosystem loss)	Consider the indirect effects of lagged environmental change on biotic interactions in biodiversity management
7	Successional changes	Loss of late-successional ecosystem structures (e.g., old growth forest stands, or deadwood)	Association with late-successional stages	Delayed decline or loss of species restricted to late-successional ecosystem structures (e.g., deadwood)	Ecosystem management and conservation (e.g., reserve planning)
8	Changes in biophysical processes	Changes in cycles and stocks of matter and energy (e.g., biomass or nutrient cycling)	Species ecology	Delayed changes in cycles and stocks of matter and energy	Sustainable use of natural resources needs to take into account delayed responses of biophysical processes

9	Selective removal of species (overharvesting)	Fishing, hunting, poaching, and collecting wild plants	Interaction of the species with the removed species (e.g., prey or competition)	Delayed decline or loss of overharvested species; delayed indirect effects (e.g., mesopredator release); delayed genetic changes of the removed species (e.g., due to new size-specific selection pressure)	Accounting for population biology and demography and indirect effects when setting harvesting caps
10	Species transport or invasions	Anthropogenic translocation; introduction and spread of species	Association with human transport pathways; dispersal capacity; population dynamics	Delayed establishment, range filling and population density equilibrium	Preventive measures (e.g., regulations, border inspections, or phytosanitary measures); eradication and containment measures
11	Evolutionary changes	Evolutionary responses to environmental changes	Genetic diversity; adaptive capacity	Delayed evolutionary adaptation to changing forces	Monitor genetic diversity and consider programs to maintain diversity
12	Adaptive changes	Adaptive responses (e.g., behavior or phenology) of species to environmental changes	Phenotypic plasticity	Delayed adaptive changes to changing forces	Difficult to integrate into management decisions

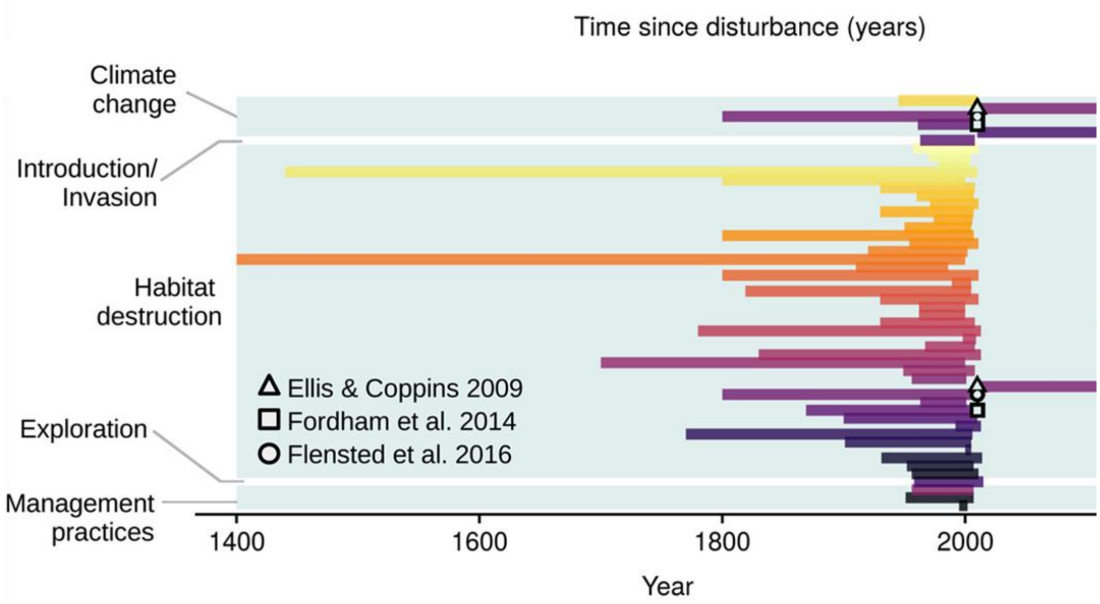


Figure 2.1 *Duration of time lags in extinction, and the drivers responsible for them. The figure shows the durations of the lags reported by empirical studies. The age (time since perturbation) and duration of the extinction debt due to the drivers generated is represented by the length of the horizontal bars. In a few cases we have projections for the duration of the extinction process into the future (*Source*: Figueiredo* et al. *2019).*

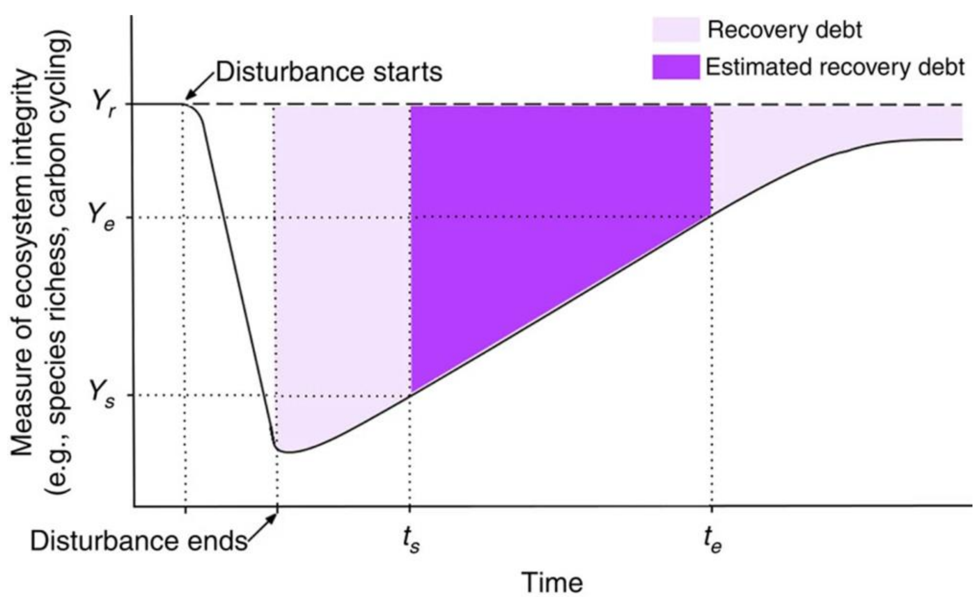


Figure 2.2 *An idealized trajectory of biodiversity loss and recovery over time following the initial disturbance. The colored zone indicates the period during recovery when biodiversity and ecosystem processes are being lost (the recovery debt;* Source*: Moreno-Mateos* et al*. 2017).*

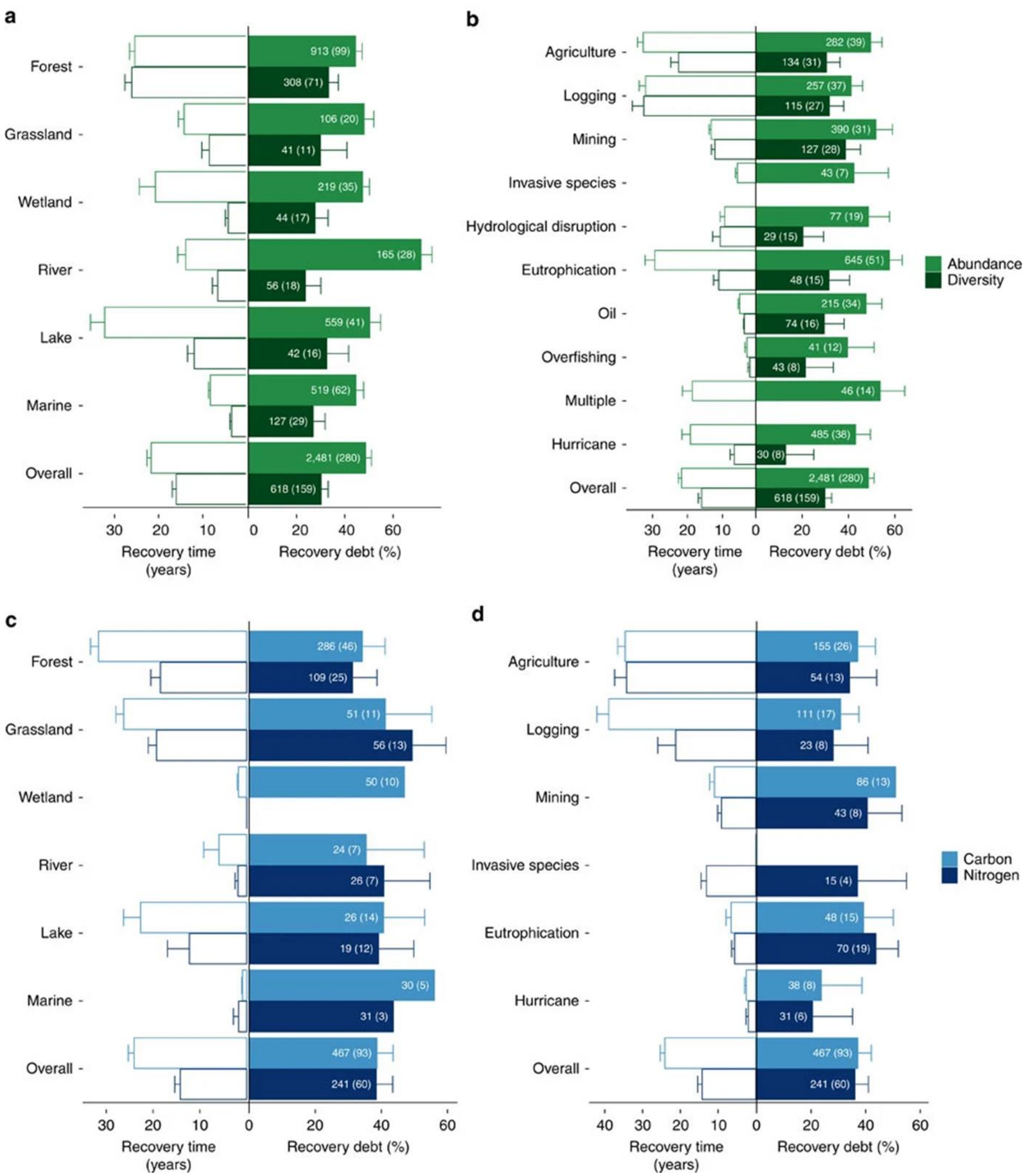


Figure 2.3 *Recovery debt per annum estimated across categories of biodiversity (abundance and diversity in green), ecosystem measures (carbon and nitrogen in blue), ecosystem type and driver impact categories. Recovery times on the left of each panel are the mean and standard error of the time since recovery started associated with each recovery debt value (*Source*: Moreno-Mateos* et al*. 2017).*

2.3 Statements summarising the evidence

2.3.1 Drivers have long-lasting effects on biodiversity

2.3.1.1 Following abrupt land cover change, local biodiversity often continues to change due to lagged responses to the perturbation. Abrupt land change in the past continues to influence present species assemblages globally. Recent data analysis and synthesis using the PREDICTS database found that biodiversity recovered to levels comparable to unchanged sites after ~10–100 years (Newbold *et al.* 2015; Jung *et al.* 2019). Ignoring delayed impacts of abrupt land changes will result in incomplete assessments of biodiversity change.

2.3.1.2 Extinction debts are a major form of delayed response to drivers. Extinction debts occur following habitat loss (Haddad *et al.* 2015; Löffler *et al.* 2020) and climate change (Lewthwaite *et al.* 2018; Vaughan & Gotelli 2021). A recent review (Figueiredo *et al.* 2019) reports extinction debts for a range of ecosystems and taxonomic groups, with estimates of the size of the debts ranging from 9 to 90% of current species richness. The duration over which debts have been sustained varies from 5 to 570 years, and projections of the total period required to settle a debt can extend to a 1000 years (Figueiredo *et al.* 2019). Long lags are also apparent for genetic diversity, particularly in long-lived species (e.g., Jackson *et al.* 2016), with some estimates being millennia (e.g., Davis *et al.* 2018).

2.3.1.3 Invasion debts are widespread in many parts of the world due to historical legacies of human land use and economic activity. An invasion debt arises because many introduced species have yet to reach their full invasion potential (Rouget *et al.* 2016). The evidence points to the widespread presence of invasion debts that can extend for decades (Essl *et al.* 2011) with long-lasting impacts on ecosystem processes and ecosystem services. This is also apparent in marine environments, where the presence of invasive alien species is often not even detected until many years after incursion, and competitive exclusion or predatory elimination of native species can take decades. As the climate changes, increasing numbers of species will be released from previous abiotic constraints, magnifying such invasion debts (while the reverse could happen too, reducing the invasion severity of some species).

2.3.1.4 There is growing evidence for widespread climatic debts. Climatic debts are the difference between the observed climate condition (e.g., temperature) and the condition at which the observed community would be at equilibrium with the climate (Vaughan & Gotelli 2021). Different taxonomic groups can show distinct climate debts over a long period (Devictor *et al.* 2012). These can arise because evolutionary change in species traits can occur long after rates of selection due to climate change have stabilised (Norberg *et al.* 2012). At large scales the climate debt is the gap between the required and realised species range shifts under changing climates. Climatic debts accumulate when species are unable to track shifting conditions sufficiently rapidly to keep pace with climate change (Bertrand *et al.* 2016).

A potential climate debt is building up in the marine environment through ocean acidification. This process may negatively affect survival of marine organisms with calcium carbonate structures in their shells or skeletons. Currently, it is not well understood exactly how or when biodiversity will be affected, or at what level of acidification the marine environment will reach the critical "tipping-points" at which each species can no longer survive.

<u>2.3.1.5</u> The longer the lag time, the greater is the probability of underestimating the full extent of biodiversity change and loss. Nonlinear behaviour in cause–effect relationships characterised by substantial lag phases means there is a high probability of underestimating the rate and duration of biodiversity change, even when a tipping point of an ecological system has already been crossed (Scheffer *et al.* 2009). For example, effects of chronic nutrient pollution can be difficult-to-reverse, due to the self-perpetuation and persistence of invaded, low-biodiversity communities, decades after the cessation of nutrient inputs (Isbell *et al.* 2013).

2.3.2 The extent of recovery after perturbation

<u>2.3.2.1</u> Ecosystem recovery from human disturbance is rarely complete. A recent synthesis found that recovery from large-scale disturbances – such as oil spills, agriculture, and logging – can occur, but that ecosystems rarely recover to their former state (Jones *et al.* 2018). Recovery rates slow down with time post disturbance, indicating that the final stages of recovery are the most challenging to achieve and require persistent and lasting action. Active restoration results in faster or more complete recovery than simply ending the disturbances ecosystems face.

<u>2.3.2.2</u> Recovery debts are widespread as ecosystems recover following disturbance. Ecosystem recovery from anthropogenic disturbances, either without human intervention or assisted by ecological restoration, is increasingly occurring worldwide. However, biodiversity can be lost even during recovery. A recovery debt is the deficit in biodiversity and ecosystem functions that accumulate during the process of recovery. A recent meta-analysis found that compared with reference levels, recovering ecosystems run annual deficits of 46–51% for organism abundance, 27–33% for species diversity, 32–42% for carbon cycling and 31–41% for nitrogen cycling (Figure

2.3; Moreno-Mateos *et al.* 2017; Dubois *et al.* 2019). As ecosystems progress through recovery, it is important to estimate the deficit in biodiversity and functions that have accrued as we move from one milestone to the next.

2.3.2.2.1 Recovery debts are particularly pronounced and prolonged in the marine ecosystems, where both environmental and biological changes often occur on longer timescales. Recovery of species diversity and ecosystem functioning within marine protected areas (MPAs) is known to take many decades after initial protection from anthropogenic disturbance and harvesting (Shears & Babcock 2003; Edgar *et al.* 2014). Recovery of genetic diversity within over-harvested marine species is likely to take many generations, especially for long-lived species such as the great whales (Jackson *et al.* 2008, 2016).

2.3.3 Impacts of lagged biodiversity change on ecosystems

2.3.3.1 Failure to consider widespread cumulative time-lags will mask the full extent of the effects of biodiversity change on ecosystems and the processes that support biodiversity. These legacies of past effects of drivers can lead to ecosystem functioning debts - delayed effects on the structure and function of ecosystems (e.g., Gonzalez & Chaneton 2002). Lagged responses of diversity to drivers can cascade to affect ecosystem processes and nature's contributions to people. These effects are relevant for human livelihoods via long-term changes in the provision of ecosystem services (Brauman *et al.* 2020). The long-term changes in nature's contributions to people (Essl *et al.* 2015b) in the form of biodiversity-dependent ecosystem service debts has been estimated for carbon storage in terrestrial ecosystems (Isbell *et al.* 2015).

2.3.4 Implications for conservation and restoration action

2.3.4.1 Conservation is needed in areas with high biodiversity debts. High debt hotspots may be situated in areas that do not necessarily spatially overlap with hotspots of species richness or high extinction-risk areas based on IUCN threatened status. This spatial mismatch suggests that conservation efforts should also be directed toward high-debt areas where there is still a window for conservation action to prevent extinction debts from being paid (Wearn *et al.* 2012; Chen & Peng 2017).

2.3.4.2 Restoring landscapes by increasing habitat area and connectivity can increase immigration credits and so reduce extinction rates and lessen the magnitude and duration of an extinction debt (Newmark *et al.* 2017; see Appendix 2.1, Box 2.1). Immigration credits are the number of species that will eventually immigrate because of a suitable environment and opportunity that represents a positive input to biodiversity (see Glossary).

The time needed for safeguarding and restoring ecosystem structure, function and resilience is particularly critical for people and communities whose livelihood and well-being directly depends on these systems and the benefits they provide (Dubois *et al.* 2019). As traditional diversity-rich human landscapes are the outcome of the long-term activities of such communities, actively involving and supporting their bottom-up initiatives in monitoring and restoration can help reach conservation and restoration targets more effectively (Anderson & Barbour 2003; Garnett *et al.* 2018; Reyes-García *et al.* 2019; Fischer *et al.* 2021).

2.3.4.3 Indicators for the time duration and magnitude of biodiversity lags are needed. Long lag times increase the importance of choosing the appropriate biodiversity variables and indicator sets to monitor. Traditional ecological knowledge can inform these choices (Savo *et al.* 2016; Lyver *et al.* 2017; Thompson *et al.* 2020). Leading indicators, indicators that provide an estimate of expected change, should be included (Halley *et al.* 2016; Hugueny 2017; Stevenson *et al.* 2021), because they provide early indications of changes in the long-term trends. Given the very rapid loss and slow recovery of genetic diversity, some of the new and rapid measures of genetic biodiversity should be used for monitoring its changing state (e.g., Hoban *et al.* 2020; Thomson *et al.* 2021).

Technical Section 3: Space and Drivers

3.1 High-level findings for the global biodiversity framework

3.1.1 The degree of biodiversity change, and relative importance of drivers, vary greatly across scales and from place to place, and drivers in one place can affect biodiversity in another. As a result, responsibility for addressing the biodiversity change, and its drivers, also varies.

3.1.2 Global targets of the GBF need to be designed in ways that allow them to be adequately and equitably disaggregated across scales, and in particular at the national level, so that the sum of national targets meets the global ambition.

3.1.3 An 'adequate' disaggregation of targets relates to the sufficiency of efforts. This includes the intensity and effectiveness of national actions, as well as the appropriate and efficient coordination of actions across countries, and including non-state actors.

3.1.4 An 'equitable' disaggregation of targets relates to the responsibility for drivers affecting global biodiversity. This means simultaneously taking into account i) the global importance of biodiversity in different national contexts, ii) the differing responsibilities for the drivers of impacts on biodiversity over time (past, present and future) and across spatial scales (telecoupling), and iii) the unequal national capacities of countries to engage in transformative change to curb drivers of biodiversity loss.

3.1.5 The targets and monitoring framework of the GBF need to be designed to enable this cross-scale analysis of biodiversity and driver change. They should also address accountability for actions and means of implementation of both Parties and non-state actors. That way, the targets and monitoring framework will support both integration and disaggregation of national responsibilities for achieving targets, including on resource needs, from subnational up to global scales.

3.1.6 During the development of the post-2020 global biodiversity framework, and even more so during its implementation, international collaboration should be strengthened, and more focused than it is now, on how to adequately and equitably share the efforts in mitigating drivers leading to the loss of biodiversity and acting upon its restoration.

3.2 Plain-language summary

Biological processes vary over multiple geographic scales from global to local, so the responsibility of countries varies with the biodiversity they host. Translation of targets and measures from the global scale to regional, national and smaller scales may not be linear or direct (Visconti *et al.* 2019), such that some countries shoulder disproportionate responsibilities for conserving biodiversity on their territory. Drivers of biodiversity loss also vary across scales from global to local, vary in their action across scales and locations, and the source of the driver may be distant from the location of impact, so the responsibility of countries varies with the drivers they impose. Teleconnections in driver-impact relationships, such as in relation to trade, migrations, climate change, transboundary pollution, etc. must be taken into account, such that responsibility to reduce drivers and reverse and/or restore biodiversity loss is equitably allocated.

This spatial variation of biodiversity, drivers and their interactions means that there is co-variation and co-dependency in implementing targets, in a very context specific manner. There are two main corollaries of this: first, the targets and monitoring framework of the GBF need to be designed to enable this cross-scale analysis of biodiversity and driver change, address accountability for actions and means of implementation of both Parties and non-state actors, and support both integration and disaggregation of national responsibilities for achieving targets, including on resource needs, from national up to global scales. Second, minimum attainment of some targets may require over-achievement of others, requiring a multi-faceted approach that must be supported by spatial planning (i.e., Target 1). This further reflects holistic goal setting as recommended by Díaz *et al.* (2020) and is similar to the ‘indivisibility’ concept of the SDGs (see Section 1).

Within the larger (global or regional) context, each location or country may need to prioritize action on the set of targets that are the most critical to their contribution to achieving global goals. Global optimization for solutions (Dinerstein *et al.* 2020; Leclère *et al.* 2020; Strassburg *et al.* 2020; Jung *et al.* 2021; Sala *et al.* 2021) can help to identify what dimensions of biodiversity, and drivers, each country or actor needs to prioritize in order to meet their contribution to the global solution. This must be complemented by localized target-setting anchored in local communities, with stakeholders and indigenous peoples (Obura *et al.* 2021; Zhu *et al.* 2021), to assure local priorities and interests are also met, including provision of benefits to people (Barnes *et al.* 2018; Mehrabi *et al.* 2018; Schleicher *et al.* 2019). This further stresses the need for metrics and indicators that enable upwards integration of data to global levels and downward disaggregation to national and more local scales relevant to actors, as is most appropriate.

The different responsibilities of countries to contribute to global efforts on biodiversity have so far mostly been addressed through the mobilisation of resources (e.g., Rio Principles, CBD Article 20). In addition to this, the implementation of the post-2020 global biodiversity framework will require strengthening international collaboration to identify which efforts and resources should be applied at the scales and locations required, integrating efforts across areas of national jurisdiction while taking into account teleconnections across geographies.

3.3 Statements summarising the evidence

3.3.1 Biological (ecological) processes vary over multiple geographic scales from global to local, so the responsibility of countries varies with the biodiversity they host as well as the remote biodiversity that their actions affect.

Scales may vary from global through multiple intermediate levels (e.g., Carmona *et al.* 2016) that may correspond to continents, ocean basins, regions, watersheds, ecoregions and/or zones. Species range sizes vary from pan-global (e.g., migratory birds along the East Asian-Australasian Flyway) to local on the order of square kilometers (e.g., Gaston & Fuller 2009). Rich spots of biodiversity are well established, such as the tropical forests in the Andes Mountains, and coral reefs in the Coral Triangle (see for example https://www.conservation.org/priorities/biodiversity-hotspots). For restricted-range species, 20 countries hold more than three quarters of single-country endemics globally, while most countries harbor fewer than 10 restricted-range species each. Half of the world's terrestrial vertebrates span their distribution across nine countries on average (median = 4; Oliver *et al.* 2021). Biological interactions and processes vary across scales, such as of migration, reproduction, foraging ranges, nitrogen fixation, amongst others.

Thus, the translation of targets and measures from the global scale to regional, national and smaller scales may not be linear or direct, as shown by different results for achieving global protected area or restoration goals globally vs. nationally (Montesino Pouzols *et al.* 2014; Dinerstein *et al.* 2020; Strassburg *et al.* 2020; UNEP-WCMC & IUCN 2021).

3.3.2 Drivers of biodiversity loss also vary across scales from global to local, vary in their amplitude across scales and locations, and the source of the driver may be distant from

the location of impact, so the responsibility of countries varies with the drivers they impose as well as the responses that are required.

Some drivers and pressures are density-dependent, being highest where human population density is high. Some can happen where human density is low but are related to specific activities, such as deforestation, harvesting of species, land use change for intensive agricultural expansion, coastal infrastructure, etc. Thus the spatial pattern of drivers and pressures must be considered in reducing their impacts**.**

Drivers and their impacts on biodiversity may be separated in space (a phenomenon known as teleconnection) and time (lags, see Section 2), based on the behaviour of the species/ecosystem (e.g., effects on a migratory species in one place may affect its role and functions in another place) and/or of the driver (demand for a product in one place may drive its exploitation and decline in another).

The relative importance of different drivers, their effects on biodiversity and of responses to them also vary over scales and space. In an assessment of the global efforts that are necessary to reduce the extinction risk for terrestrial mammals, birds and amphibians, five countries were together found to be responsible for over 31% of the global effort needed to mitigate threats to these species while the least-scoring 88 countries together were found to be responsible for only 1% of the global effort (Mair *et al.* 2021).

Given the combined effects of different drivers, human activities can elicit biodiversity responses across multiple scales, requiring management responses at a variety of temporal and spatial scales. One lesson from the Aichi Targets is that scalability of a target did contribute progress in achieving them (Green *et al.* 2019). However, this sort of nestedness has so far been the exception rather than the rule in biodiversity governance, and this is a clear area where progress is needed for the post-2020 global biodiversity framework and its monitoring.

Thus efforts to meet locally-scaled global targets may require inputs from multiple global sources both to reduce (and/or reverse) drivers sufficiently to allow a positive biodiversity response, and to implement responses to facilitate bending the curve of biodiversity trends. Understanding these cause-effect relationships can be used to identify responsibility and resourcing for action on drivers and responses, acknowledging differential capabilities among actors and countries. This establishes a complementary responsibility to 3.3.1 that relates to responsibility for addressing the drivers of decline, which may include actions to reverse historical losses and to prevent future declines.

3.3.3 Spatial variation of biodiversity, drivers and their interactions means that there is co-variation and co-dependency in implementing targets.

For example, achieving genetic targets may be necessary to assure species targets; one cannot be achieved without the other (Díaz *et al.* 2020). As a result, minimum attainment of some targets may require over-achievement in others, requiring a multi-faceted approach that is supported by spatial planning (Target 1), and considers multiple spatial scales. This reflects holistic goal setting as recommended by Díaz *et al.* (2020) and is similar to the 'indivisibility' concept of the SDGs (see Figure 1). The Ecosystem Approach, developed in the context of the CBD, aims at fostering such integrated approaches.

These spatial interactions also mean that biodiversity, drivers and their interactions may show co-variation and co-dependency among targets, reinforcing the message that targets may not be addressed singly or in isolation. Ensuring different drivers and the impacts these exert on dimensions of biodiversity are holistically dealt with is key for conservation and sustainable use to be simultaneously considered. Holistically dealing with drivers and their biodiversity impacts is essential for human-induced pressures as well as human well-being and cultural diversity to be fully integrated into an overarching management approach (the Ecosystem Approach). This must be complemented by localized target-setting anchored in stakeholders, with a special focus on stakeholders and indigenous peoples and local communities to assure local and national priorities and interests are also met, including ensuring the provisioning of nature's contributions to people. Area-based conservation needs to be more closely aligned to the needs and mechanisms of indigenous peoples and local communities and private initiatives for greater success at achieving biodiversity goals in the future (Maxwell *et al.* 2020; UNEP-WCMC & IUCN 2021).

3.3.4 Indicators to assess achievement of targets can aid the process of adequately and equitably allocating shares of responsibilities in meeting locally-scaled global targets.

Accounting for the share of the distribution of a given ecosystem or species across countries is a simple and effective way to adequately and equitably allocate area-based conservation targets at the national level, and to direct spatial planning effort, as well as consistently track progress

(Oliver *et al.* 2021; Tulloch *et al.* 2021). Where possible, targets should be designed in ways that make this translation and downscaling possible based on accounting mechanisms and estimated national responsibilities.

Accounting for the share of the distribution of a given driver of biodiversity decline may be more challenging, given the complex links between drivers (direct and especially indirect) and state of biodiversity, their potential telecoupling over space, and time lags in action. Nevertheless, key direct and indirect drivers are established (IPBES 2019) and grossly allocable by sector using sectoral indicators (e.g., agriculture and food, transport, mining, etc., IPBES 2019) and by country using development and trade indicators. These indicators may be used in addition to the GBF-specific indicators to allocate and account for responsibility among countries (e.g., Adams *et al.* 2021) and by non-state actors such as in industry, transport, agriculture, fisheries and other sectors. Science-based targets addressing this challenge of detection and attribution (see Section 4) are under development; these targets can quantify impacts by different actors and along value chains (Andersen *et al.* 2021; Rockström *et al.* 2021).

3.3.5 Strengthening international cooperation, including joint commitments to action, will be critical to meet multi-scale driver-impact-response relationships to achieve global targets.

The complexity of driver-impact-response relationships (Figure 1) requires trans-jurisdictional cooperation, which will be necessary for countries and actors to meet multi-level targets in optimal ways, and adopt a spatial scale for cooperation needed to achieve this. For example, EU nature/wildlife management (terrestrial and marine) is more successful than what was previously being achieved on a country-by-country basis (Campagnaro *et al.* 2019); benefits of international cooperation are clear in several river management initiatives (e.g., Danube River Protection Convention[4]; the Benguela Current Commission[5] which is an initiative between Angola, Namibia and South Africa aimed at an ecosystem approach to ocean governance off the coast of southwest Africa, see Figure 3.1). Furthermore, lessons learned in one region can also provide insights on issues encountered in other regions: inter-regional partnerships and emulation could help increase collective knowledge on how to address drivers of biodiversity loss and support transformative change (Rankovic *et al.* 2020).

[4] https://www.icpdr.org/main/icpdr/danube-river-protection-convention
[5] https://www.benguelacc.org/index.php/en/

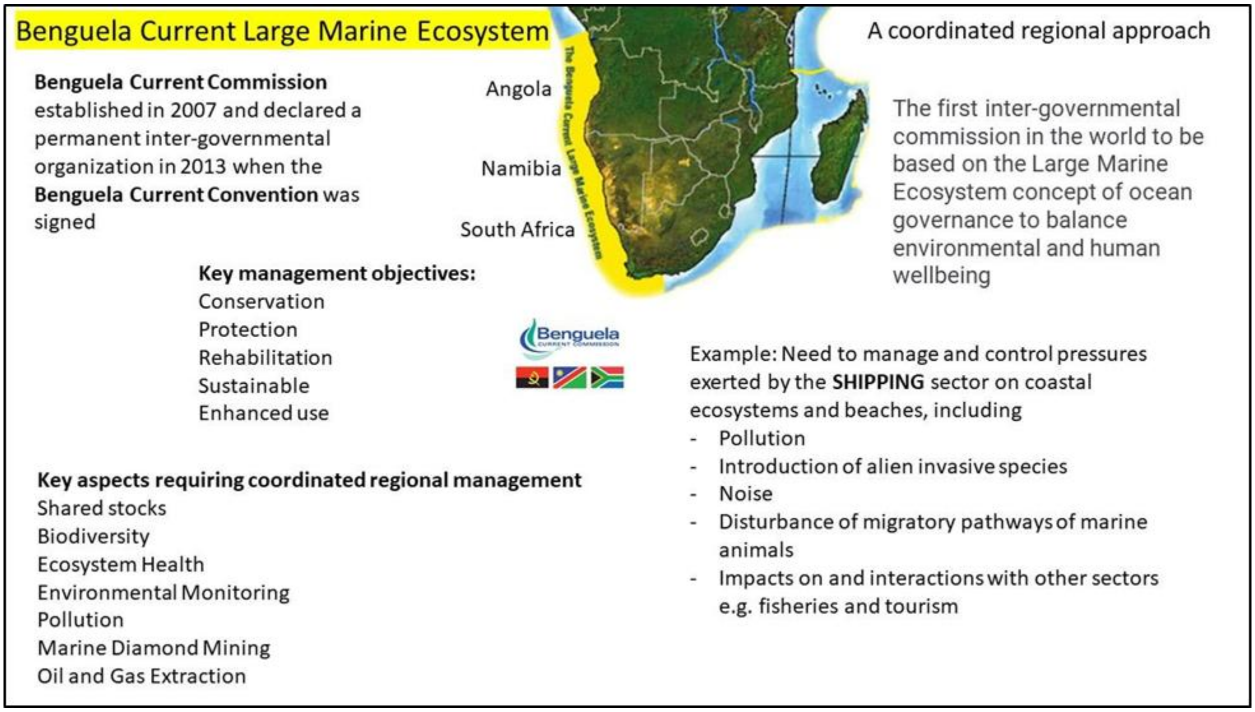


Figure 3.1 *Schematic summary of the Benguela Current Commission aimed at holistic management of the Benguela Current Large Marine Ecosystem off South-western Africa (*Source: *produced from information available online[6]).*

3.3.6 Within the larger (global or regional) context, each location or country may need to prioritize action on the set of targets that are the most critical to their contribution to achieving global goals.

Global optimisation for solutions (Dinerstein *et al.* 2020; Leclère *et al.* 2020; Strassburg *et al.* 2020; Jung *et al.* 2021; Sala *et al.* 2021) can help to identify what subset of components of biodiversity, and drivers, each country or actor needs to address to meet their contribution to the global solution. Complementing these with localized target-setting (Obura *et al.* 2021; Zhu *et al.* 2021) to assure local priorities and interests are met, including of benefits to people (Barnes *et al.* 2018; Mehrabi *et al.* 2018; Schleicher *et al.* 2019) can assure local and national interests are met within the shared global goals of the GBF. An example of such an approach is provided by Conservation of Arctic Flora and Fauna (CAFF 2015): Actions for Arctic Biodiversity 2013-2021, whereby actions have been continuously assessed and recommendations refined in line with regular progress reports.

[6] https://www.benguelacc.org/index.php/en/

Further, considering how actions are implemented, national priorities and planning are essential and different countries will have different needs that must be met to support implementation. These may include variation in capacity among countries to manage biodiversity and natural resources, requiring transfer of knowledge, and financial and other means.

3.3.7 Meeting the resource needs for achieving the global biodiversity framework is a global responsibility, with differential roles to be filled among countries, regions and different actors, for generating these resources, in order for them to be applied at the scales and locations required.

Assuring resources are directed based on responsibility for drivers to responsibility for biodiversity will be essential for success to assure upscaling of resources is sufficient to the task, in the current context where the need for financial resources to support transformative change in different key sectors is still not met (e.g., Deutz *et al.* 2020).

The majority of Earth's biodiversity is found in developing countries (e.g., countries in the tropics; Barlow *et al.* 2018), and thus the locus of action for conservation lies within the jurisdiction of these countries. However, drivers act across national boundaries, for example, those related to international trade (Lenzen *et al.* 2012) and climate change (IPCC 2014). Further, the effectiveness of conservation actions has not been at a sufficient level to meet historical needs (Zafra-Calvo *et al.* 2019), and management effectiveness is especially challenging in developing countries (Cochrane 2021). Mechanisms that account for these global disparities, and responsibility and capacity to bear costs, will need to be established to ensure fair sharing of conservation burden among countries (UNEP-WCMC & IUCN 2021).

Further, considering how actions are implemented, national priorities and planning are essential and different countries will have different needs that must be met to support implementation. These may include variation in capacity among countries to manage biodiversity and natural resources, requiring transfer of knowledge, and financial and other means.

Technical Section 4: Monitoring

4.1 High-level findings for the global biodiversity framework

4.1.1 Current biodiversity monitoring and information infrastructures have proven to be effective in developing indicators of biodiversity change. Additional investment in biodiversity monitoring infrastructure and information workflows will allow the monitoring of drivers to enable a detection and attribution methodology for biodiversity trends. This investment will support new indicators and the data needed to assess whether actions on drivers are leading to intended outcomes for biodiversity.

4.1.2 Available biodiversity data and monitoring capacities are unequally distributed across the globe. Enhancing local and national capacities to generate and deliver biodiversity information will increase the capacity of different stakeholders to produce and use biodiversity information in strategic planning and assessment processes. Linking bottom-up and top-down approaches in the production of headline indicators will encourage their use by local and national governments.

4.1.3 The role of indicators in implementation of the GBF can, and should, extend well beyond monitoring progress toward individual targets and goals. If indicators are designed and used properly, and are supported by robust data, they can also play a vital role in prioritizing and planning actions, promoting adaptive management and ensuring that actions contribute to the achievement of outcomes as effectively and efficiently as possible.

4.1.4 The biodiversity monitoring framework of the GBF needs not only to identify indicators but to provide a logic behind them that allows the assessment of the interdependencies between action and outcomes. The detection of biodiversity trends and the tracking of progress towards goals, milestones and targets, will require adequate monitoring of drivers and all dimensions of biodiversity with the use of essential biodiversity variables. This will improve the monitoring of drivers and actions, but also establish an operational detection and attribution methodology linking targets to outcomes.

4.2 Plain-language summary

Biodiversity observation

Biodiversity observation systems range from local to regional spatial scales and cover a variety of taxonomic and thematic dimensions of biodiversity (genes, traits, species, populations, communities, ecosystems). Biodiversity is monitored to gather information about the status of different biodiversity dimensions and the essential variable(s) that measure them at different points in time for the purpose of assessing the state of the system and drawing inferences about changes in state over time. Biodiversity data form the basis of monitoring and are derived from systematic and structured observations (i.e., observations made at the same location and time, using standardised methods) typically made across a monitoring network supported by a government or umbrella organization. A growing amount of biodiversity data also derives from observations reported by individuals (e.g., citizen observations recorded with digital applications such as iNaturalist).

Overall, the number of biodiversity observations has increased immensely, especially in recent years. Observations of biodiversity come from different sources including those made on-the-ground (*in-situ*) and those made remotely from the air, water or from orbit using satellite imagery (Bush *et al.* 2017). The Global Biodiversity Information Facility (GBIF) now reports nearly two billion observations that are publicly accessible (https://www.gbif.org/). The growth in data, and the availability of new datasets, are driving more powerful and robust analyses of biodiversity change (e.g., Newbold *et al.* 2015; Blowes *et al.* 2019; Daskalova *et al.* 2020; Millette *et al.* 2020; Leigh *et al.* 2021). However, well-known geographic and taxonomic biases exist in global data (Pereira *et al.* 2012; Schmeller *et al.* 2017). Human drivers of biodiversity change are not systematically monitored and used to attribute causes of reported trends. There are also considerable inequities in the capacities of different nations and communities to collect and share data. The result is the presence of large spatial, historical, taxonomic and thematic gaps in available biodiversity information, which constrains our ability to generate more robust inferences about biodiversity change using existing biodiversity indicators.

Indicators of biodiversity change

The production of indicators relies on the data that underpin them and our capacity to implement workflows from data to indicators (Figure 4.1). Following Jones *et al.* (2011) we use the term “monitoring” (see Glossary) to refer to the process that includes the collection of primary biodiversity data, synthesis of data into an indicator and public dissemination of trends in the indicator.

Indicators are typically organised under specific frameworks that relate different types of indicators for representing different dimensions of a problem or situation that needs to be managed. Some of the frameworks used to relate indicators include driver, pressures, state, impact and response (DPSIR), or pressure, state, benefit and response (PSBR), and are useful for establishing conceptual “detection-attribution” relationships (Sparks *et al.* 2011; Driscoll *et al.* 2018; Stevenson *et al.* 2021).

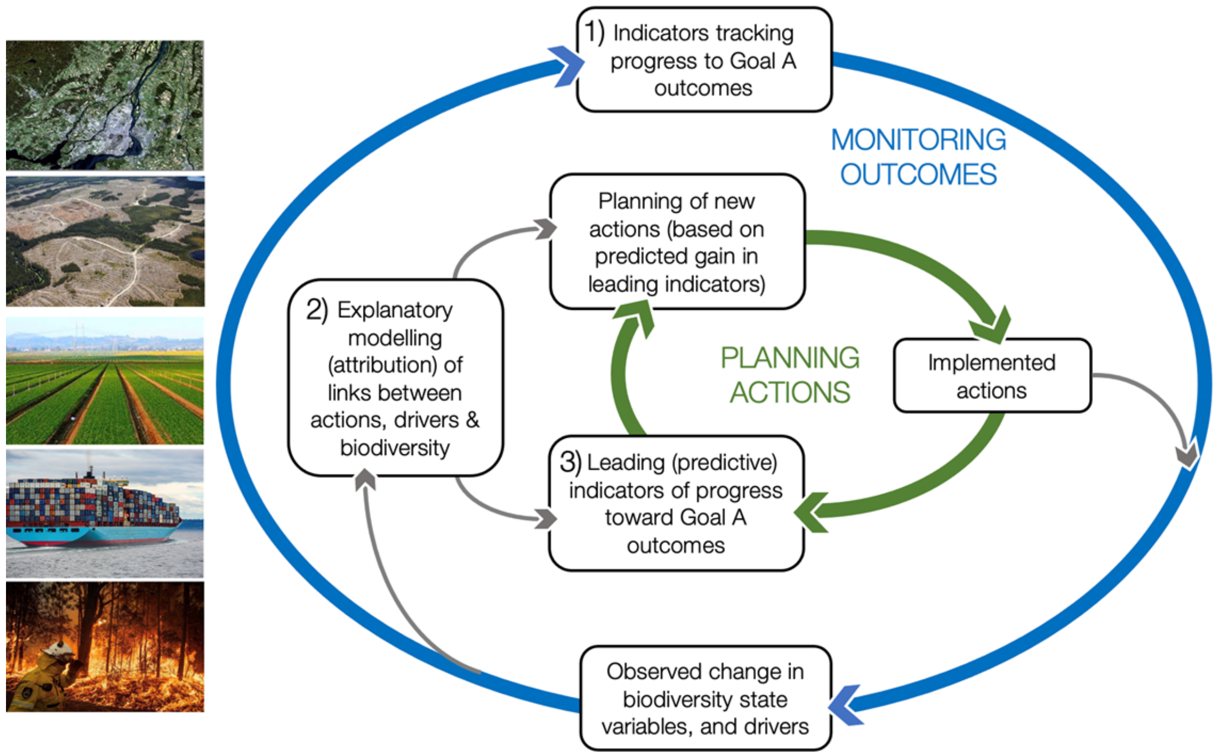


Figure 4.1 *The iterative cycle of monitoring and action guided by explanatory models and indicators. The outer blue cycle refers to monitoring of actual changes in biodiversity and the updates in indicators used to track progress to Goal A outcomes (box 1). The inner cycle refers to the role of explanatory models (box 2) and leading indicators (box 3) that incorporate understanding of the impacts of drivers (attribution) on trends in essential biodiversity variables to guide spatial planning and prioritization of conservation action.*

Monitoring for detection and attribution of drivers

Temporal trends in species and genetic diversity and high rates of compositional turnover have been reported worldwide (Blowes *et al.* 2019; Millette *et al.* 2020). In many cases, analyses achieve trend detection and only rarely are trends attributed to possible drivers (Millette *et al.* 2020). How do we detect and attribute the impacts of different forms of human drivers in the presence of natural variability in biodiversity? Answering this question requires a detection and attribution framework for biodiversity change akin to the framework used by climate scientists (Myers *et al.* 2021).

A detection-attribution monitoring framework (Figure 4.1) combines data and models to establish where and to what extent drivers are causing biodiversity change. It involves four steps: 1) observation and records of different dimensions of biodiversity, either by remote sensing (satellites, aircraft or drones), or on the ground and in the water via methods of direct observation or inferred presence (with environmental DNA), 2) the translation of raw observations into essential biodiversity variables (EBVs) that represent standardised measures adapted to the task of quantifying change, 3) trend detection using statistical models to infer, with appropriate measures of uncertainty, the rate and magnitude of change, and 4) attribution of direct drivers as causes of the change in EBVs using statistical and process based models to convey the degree of confidence in the attribution made across different locations over time. Attribution can be framed probabilistically, so that the likelihood of a biodiversity loss (e.g., extinction) or gain (e.g., species invasion) event of a similar magnitude arising from a driver can be given and predicted into the future.

Detection and attribution of biodiversity change is needed to plan and prioritise interventions designed to mitigate the effects of drivers on biodiversity. We need to progressively improve indicators that convey when critical thresholds in driver impact are being reached and transgressed. Leading indicators of biodiversity change built from explanatory models of the effects of drivers are much needed (Stevenson *et al.* 2021).

Relying on too few indicators can lead to a gap in our ability to attribute detected change to individual pressures. Similarly, relying on indicators that are underpinned by the same or closely related data-sources may miss important trends. The same framework allows statistically robust assessments of which interventions are leading to detectable changes in the targets stated in Goal A.

Linking bottom-up and top-down approaches

Biodiversity observations designed to support the monitoring needed to track progress to the GBF require both a bottom-up and top-down approach that combines information from different communities and technologies (Navarro *et al.* 2017; Eicken *et al.* 2021). A bottom-up and top-down approach promotes data integration from field-based observations made by different groups (e.g., professional biologists, local indigenous communities and citizens) using a range of technologies for *in-situ* data acquisition and sharing, with data from a top-down approach involving remotely sensed data (e.g., space agencies satellites derived products; Ferrier 2011; Kühl *et al.* 2020). But a bottom-up and top-down approach also means that locally or nationally-collected data are integrated with global indicators/databases to allow effective scaling of indicators (Burgass *et al.* 2021; Nicholson *et al.* 2021). This two-way flow of information on biodiversity change simultaneously supports decisions at national, regional and global scales.

4.3 Statements summarising the evidence

4.3.1 Only some dimensions of biodiversity can be monitored for change at this time

Current availability of biodiversity data and monitoring networks means that we are capable of analysing trends over extended periods of time and spatial extents for some groups of organisms and ecosystems. Population abundances (e.g., Leung *et al.* 2020), species composition (e.g., Blowes *et al.* 2019; Seibold *et al.* 2019) and ecosystem structure (e.g., forest extent and rates of change; Grantham *et al.* 2020) have been the focus of most regional and global assessments of biodiversity change. Detecting and attributing trends in genetic diversity at regional and global scales has only just begun (Bruford *et al.* 2017; Millette *et al.* 2020; Schmidt *et al.* 2020). The global monitoring of area, connectivity and integrity of natural ecosystems is in place for forest ecosystems (Grantham *et al.* 2020), rivers (Grill *et al.* 2019), wetlands (Davidson 2014) and coral reefs (Obura *et al.* 2019; Eddy *et al.* 2021; The Global Coral Reef Monitoring Network 2021), but is much less well established for other ecosystem types, especially managed ecosystems.

4.3.1.1 Technologies have fostered the collection and analysis of biodiversity data. Biodiversity monitoring and assessment has increased in recent decades due to the growth of new observation technologies, open access data and the development of technologies for the analysis of big data (e.g., Schneider *et al.* 2020; Pennisi 2021).

The input from citizen and community-based science initiatives to species records has increased the size of global biodiversity datasets (Bonney *et al.* 2009; Chandler *et al.* 2017). Current observations on the public biodiversity observation and recording platform iNaturalist (https://www.inaturalist.org/observations) have exceeded 80 million records, while bird sighting data recorded in eBird (https://ebird.org/) have exceeded 500 million records. This opportunistic and unstructured biodiversity observation data can be used to make valuable inferences about changes in biodiversity (e.g., Horns *et al.* 2018).

Biodiversity monitoring has also advanced globally in identifying trends in land cover change and ecosystem extent, particularly change in area of forest ecosystems and some marine ecosystems (e.g., tidal flats, ice-sheets, etc.) are frequently being monitored given the increase in remote sensing airborne and satellite imaging (e.g., Hansen *et al.* 2013). Other remote sensing derived products associated with ecosystem function such as carbon storage, primary productivity, phenological aspects and plant diversity have been also produced mainly by space agencies (Pettorelli *et al.* 2018; Wang & Gamon 2019). New satellites and improved image processing approaches are enabling the ability to provide real-time and near real-time biodiversity mapping which is fundamental for practical purposes, such as combating fire and deforestation in tropical forests (Gao *et al.* 2020). Remotely sensed data requires ongoing local-regional calibration but has significantly reduced regionalized data gaps. While these methods do not replace local data collection on many dimensions of biodiversity, the growth, availability and regularity of remotely sensed data are particularly appropriate for supporting the setting and tracking of national targets (O'Connor *et al.* 2015; Turner *et al.* 2015). Linking remote sensing with on the ground observations offers great potential for improving biodiversity monitoring.

Ocean biodiversity measurements have benefited from remote sensing of the ocean surface combined with autonomous surveys drones on water surface and global robotic measurements of the water column in data synthesizing models that provide reliable status and forecasts for the physical status and trends of the ocean (Canonico *et al.* 2019; Capotondi *et al.* 2019). Also from rapid advances in eDNA approaches (Jeunen *et al.* 2019; Bani *et al.* 2020; Eble 2020).

There have also been rapid and substantial advances in directly monitoring genetic biodiversity (e.g., Hoban *et al.* 2020, 2021a, b). This has occurred across all its aspects, including: 1) methods of direct measurement in many species simultaneously, 2) bioinformatic collation of data across large numbers of species and locations, and 3) development of useful summary parameters that can be used in biodiversity monitoring. The rate of these advances is escalating dramatically, such that reliable direct genetic indicators across a broad spectrum of biodiversity could be considered achievable and necessary by 2030.

<u>4.3.1.2</u> Global infrastructures and data sharing and quality principles have increased the availability of high-quality biodiversity data. A global biodiversity data infrastructure is being assembled but sustained investment and development is needed. Global data infrastructures such as Global Biodiversity Information Facility (GBIF) and Ocean Biodiversity Information System (OBIS) are making very large datasets available to all with internet access. The adoption

of clear data standards such as those developed by the Biodiversity Information Standards (TDWG), the Group on Earth Observations Biodiversity Observation Network (GEO BON), Global Ocean Observing System (GOOS), and the FAIR (Findable, Accessible, Interoperable and Reusable; https://www.go-fair.org/fair-principles/) and CARE (Collective benefit, Authority to control, Responsibility, Ethics; https://www.gida-global.org/care) principles for scientific data management and ethical use and stewardship, have made possible the aggregation of interoperable and open data derived from different monitoring initiatives.

4.3.1.3 Progress has also been made on designing more efficient and effective approaches to prioritizing data needs and harmonising methods**.** The development of essential biodiversity variables (EBVs), Figure 4.2, is helping to harmonise biodiversity data across spatial and temporal scales and across taxonomic groups. EBVs define a minimum set of essential measurements required to capture the multiple dimensions of biodiversity change (Pereira *et al.* 2013; Navarro *et al.* 2017). Parallel work on essential ocean variables is building availability of ocean-based biodiversity indicators to complement existing climate, physical and biogeochemical 'essential variables' (Miloslavich *et al.* 2018; Muller-Karger *et al.* 2018). EBVs and their development framework have been endorsed by the CBD (Decision XI/3) and can be used by Parties as standardised inputs from which to calculate the indicators used to report on the status of national biodiversity trends.

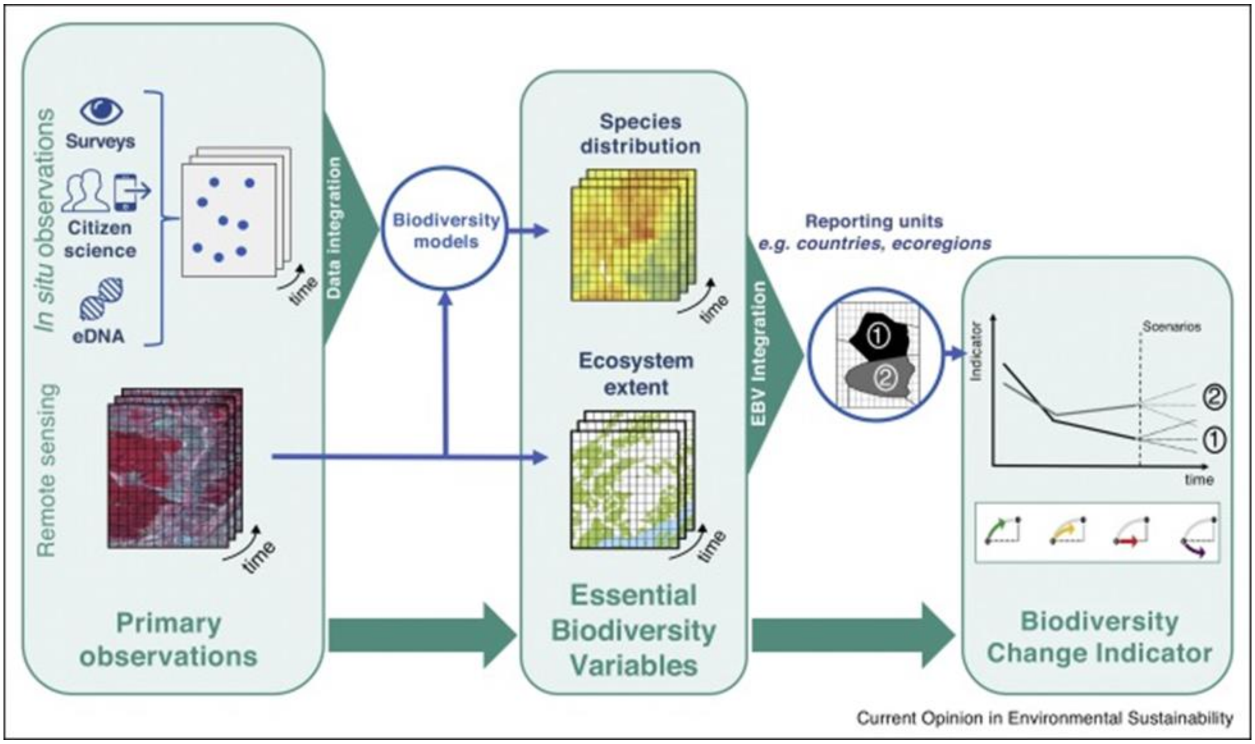


Figure 4.2 *General workflow from multiple primary biodiversity observations, to standardised essential biodiversity variables and to biodiversity change indicators (*Source*: Navarro* et al. *2017). Expert knowledge and assessment are essential for the harmonisation of data across sources and spatial scales.*

Workflows from data to indicators have been developed and implemented by conservation practitioners and national biodiversity institutes in charge of advising national governments. For example, South Africa National Biodiversity Institute has designed and implemented powerful indicators for tracking progress towards ecosystem extent, restoration and connectivity, among other indicators (Skowno *et al.* 2019). The GBF indicators should incorporate contributions from those working directly on conservation policy and action.

4.3.2 The strengthening of monitoring infrastructure and capacities is necessary for precise measurements of progress towards the milestones

4.3.2.1 Species records cover less than 7% of the world's surface at 5 km resolution, and less than 1% for most taxa at higher resolutions. To understand community dynamics, much higher resolutions are needed, especially in heterogeneous landscapes (Figure 4.3; Hughes *et al.* 2021). Monitoring capacities are highly unequally distributed across the globe resulting in bias towards certain countries; data from just ten countries account for 82% of all available records, limiting them to Europe, USA (representing 44% of the records), Australia and South Africa, while all other countries account for 18% of remaining records (Hughes *et al.* 2021). Lack of knowledge on the distribution, population trends and threats for many taxa is reflected in the large number of data deficient species on the IUCN Red List (Figure 4.4; Hochkirch *et al.* 2021), where research on "population size, distribution and trends" is needed for 47% of the species. There are many reasons for the inequitable distribution of species' data, including constraints on financial and technical capacity and inadequate political will (Stephenson 2019).

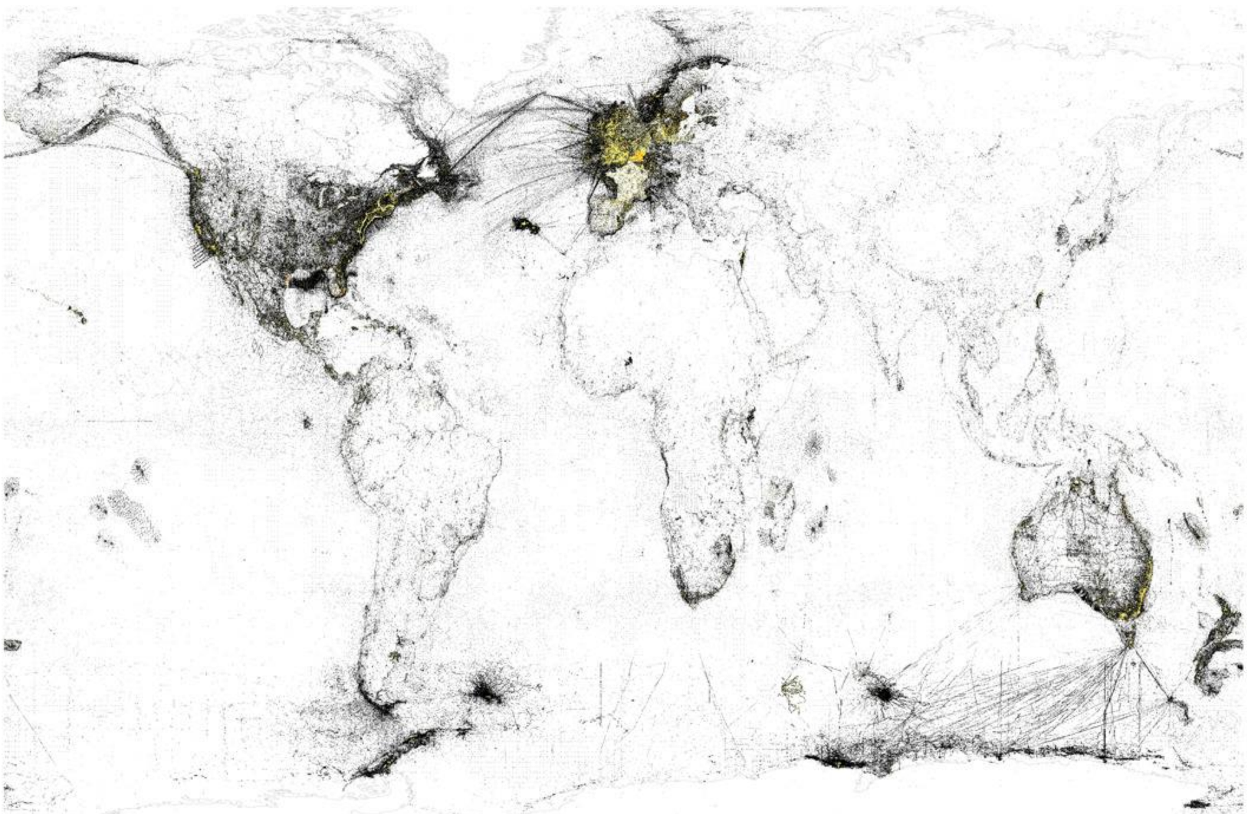


Figure 4.3 *Global distribution of sites sampled for biodiversity with high numbers of records in GBIF* (https://www.gbif.org/) *and OBIS* (https://obis.org/) *databases. At a 5 km resolution, 11% of the Earth's land (based on GBIF records) and 5% of the ocean (based on OBIS records) have been sampled. Black 1–50 records, yellow-red > 50 records (*Source*: Hughes* et al*. 2021*).

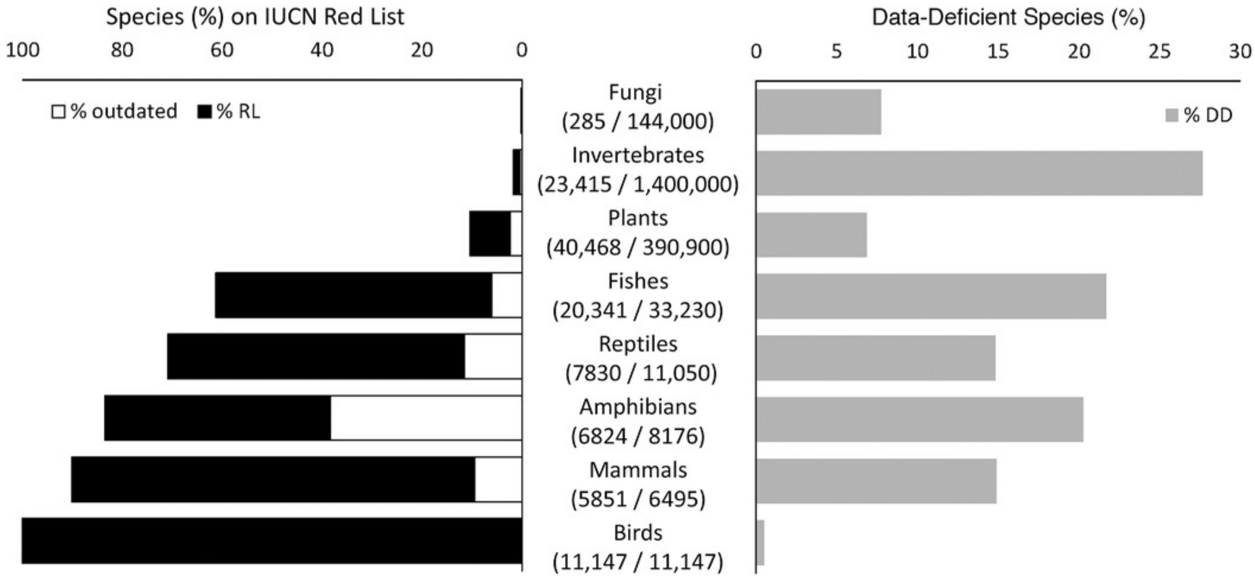


Figure 4.4 *Percentage of species (left) assessed for the IUCN Red List of Threatened Species (RL) and percentage of assessments (right) with insufficient (data deficient) information (IUCN Red List version 2020–1) (white, number of outdated [>10 years old] IUCN assessments; numbers in the center, number of species [left] on the IUCN Red List and [right] estimated number of described species;* Source*: Hochkirch* et al. *2021).*

4.3.2.2 Global freshwater biodiversity datasets contain major gaps in taxonomy, geography and ecosystem type (Cantonati *et al.* 2020). The gaps are partly a product of the history of environmental health assessments in freshwaters. On the other hand, emerging technologies have given rise to new opportunities which have the potential of closing some of the gaps. In a great variety of freshwater environments, assemblage-level indices, especially for fish and macroinvertebrates, were widely used to assess ecological health for several decades in national, subnational and regional monitoring programs (Turak *et al.* 2017b). Typically these programs had developed around national legislation and policy and were transformed into, or gave rise to, biodiversity monitoring programs. Many of these are now making major contributions to tracking global change in freshwater biodiversity but face a major challenge in harmonising sampling protocols (e.g., kick net, electrofishing, etc.) and ensuring data interoperability among countries. In contrast to traditional methods, new freshwater biodiversity monitoring methods based on emerging technology are globally consistent (e.g., eDNA, ecoacoustics). However, these methods are yet to make major contributions to global assessments of freshwater biodiversity. Although metabarcoding and eDNA have been considered for several years to be major priorities for assessing freshwater biodiversity for both 2020 CBD Targets and 2030 SDGs (Turak *et al.* 2017b), it is only very recent that a global program (eBioAtlas; https://ebioatlas.org/about/) was initiated to collect data that has the potential of making global contributions (Freshwater Blog 2021). Freshwater methods in ecoacoustics have greatly advanced in recent years but their integration into large-scale freshwater biodiversity monitoring is unlikely to happen in the near future (Barclay *et al.* 2020).

Another major impediment to global freshwater biodiversity assessments is the slow progress in the assessment of conservation status of aquatic species. For example more than 33,500 fish species inhabit freshwater and marine environments, according to the FishBase database records. The IUCN has assessed the conservation status of approximately half of them, the lowest percentage in any vertebrate group (Miqueleiz *et al.* 2020).

Only a small fraction of ocean biodiversity is monitored, 7% of the ocean surface area is represented by long-term (more than 5 years) observing programs, mostly concentrated in coastal regions of the United States, Canada, Europe, and Australia. Most of the ocean lacks long-term biological observations, including most of the open ocean and coasts of some parts of South America, Eastern Europe, Asia, Oceania, and Africa, while 22% of all countries with coastline have no identified sampling programs (Figure 4.5; Satterthwaite *et al.* 2021).

Sampling in oceans is unevenly distributed across latitudes and depths, regions around 50 degrees north and south are relatively over-sampled, mid-latitudes around the equator and the Arctic, and the bathyal, abyssal, and hadal regions of the ocean where the seafloor is deeper than 2,500 m are under-sampled (Figure 4.6; Satterthwaite *et al.* 2021). A lack of coordination of the global observation system imposes challenges for the delivery of critical information on status and trends of marine biodiversity, failing to support informed decisions for the conservation of marine ecosystems (Satterthwaite *et al.* 2021).

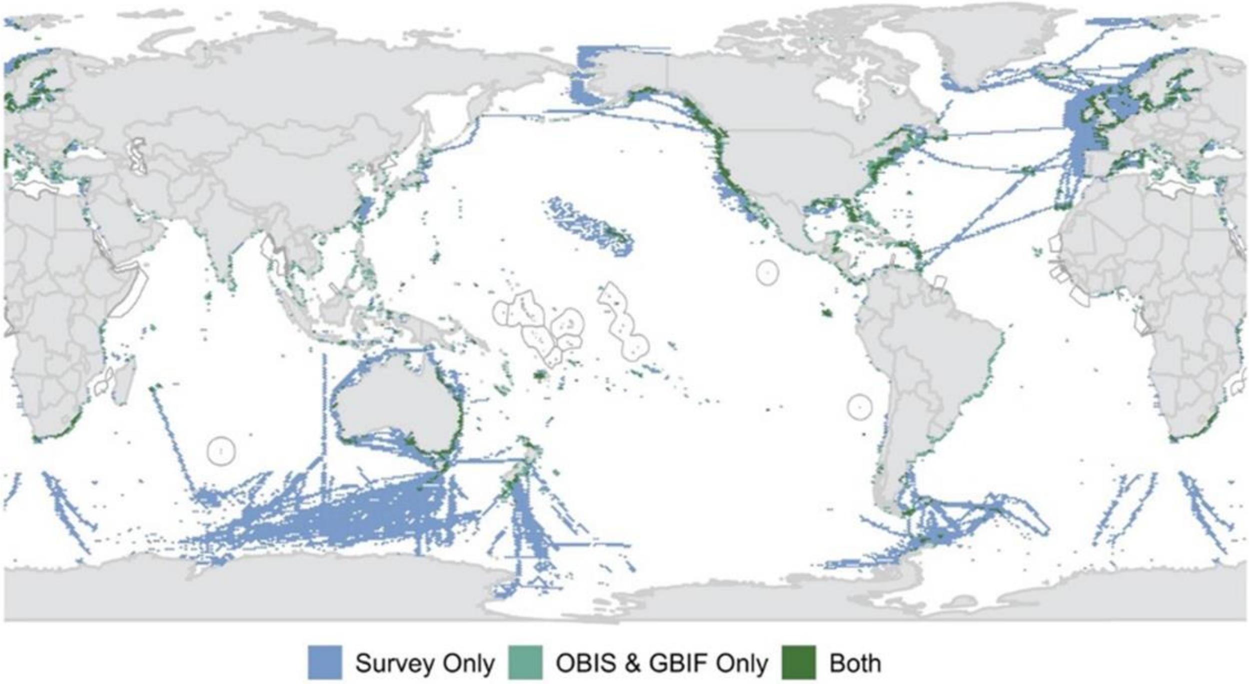


Figure 4.5 *Spatial coverage of known active, long-term biological observations globally (coloured regions). Colour indicates biological observations identified from the survey only (blue - 5% of ocean surface), from datasets in the Ocean Biodiversity Information System (OBIS) and the Global Biodiversity Information System (GBIF) only (teal - 1% of ocean surface), and those identified in both sources (green- 1% of ocean surface; map displayed across ≥ 0.5° grid cell: about 55 km*^{2} *at the equator). Gray lines show Exclusive Economic Zones (EEZ; 200 nm) of nations with no known biological Essential Ocean Variable (EOV) sampling according to this study (*Source*: Satterthwaite* et al*. 2021).*

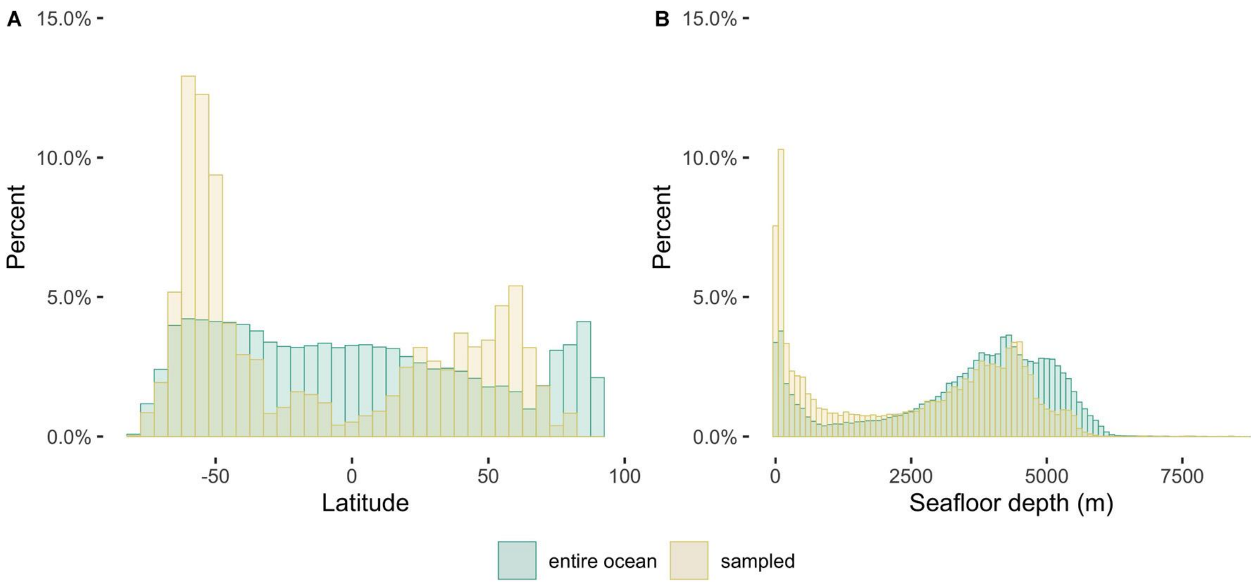


Figure 4.6 *Overlap between sampled sites and the global ocean. Histograms of latitude (A) and seafloor depth (B) for the global ocean area ("entire ocean") compared with areas sampled by observing programs in this study ("sampled"). Results include the spatial information from the surveyed programs and the datasets from the Ocean Biodiversity Information System (OBIS) and the Global Biodiversity Information System (GBIF). Bin widths are 5 degrees for latitude (A) and 100 meters for seafloor depth (B). Regions that were under sampled are characterised by the entire ocean (blue bars) being greater than the sampled areas (gold bars), with the converse for oversampled areas (*Source*: Satterthwaite* et al. *2021).*

4.3.2.3 Soil organisms support many ecosystem functions, yet important spatial, environmental, taxonomic and functional gaps in soil biodiversity exist (Figure 4.7), one of the most important gaps being the lack of temporally explicit data and studies exploring the relationship between soil biodiversity and ecosystem functioning relationships (Guerra *et al.* 2020).

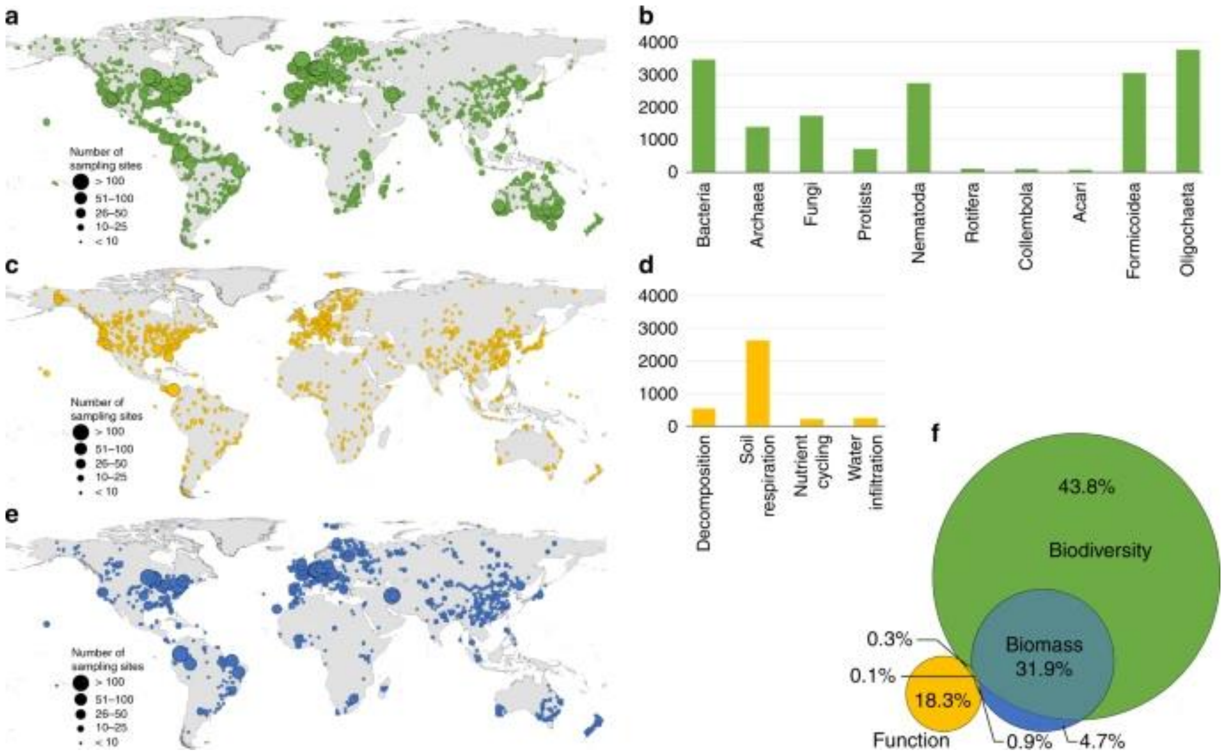


Figure 4.7. *Global distribution of sampling sites for soil taxa and soil ecosystem functions. a, b correspond to the global number of individual sampling sites for each soil taxon, c, d to the distribution of ecosystem functions, and e to the distribution of samples with biomass data. The Venn diagram (f) indicates the proportion of sampling sites for soil taxa (in green), functions (in yellow), and biomass (in blue), and the 0.3% (N = 63) of overlap between biodiversity and function data points (this number does not mean that soil biodiversity and function were assessed in the same soil sample or during the same sampling campaign), relative to the total number of sampling sites covered by the studies. The maps show the overall spatial distribution of sampling sites for all taxa (a) and soil ecosystem functions (c). The size of the circles corresponds to the number of sampling sites within a 1° grid ranging from <10 to >50." (*Source*: Guerra* et al. *2020).*

4.3.2.4 Measurement of the integrity of terrestrial ecosystems requires local knowledge and observation that differs from the measurement of changes in area. The monitoring of land cover and land use needs to be integrated with specific measures of ecosystem process, functions and biodiversity. Drivers of change can diminish ecosystem integrity through changes in composition, structure and function even if ecosystem extent remains the same (Grantham *et al.* 2020, Nicholson *et al.* 2021).

Several methods and indicators exist for measuring integrity across different ecosystem types, nevertheless, many indicators highly relevant for measuring ecosystem integrity are composed of short time series, sub-global coverage or are ecosystem specific having extensive data only for some ecosystems (Nicholson *et al.* 2021).

Ecosystem integrity focuses on the difference between land cover and ecosystem types. Area based indicators are frequently used to measure ecosystems, but there is a need to make explicit the link between the feature mapped and the ecosystem represented (Nicholson *et al.* 2021). For example, forest/non-forest indicators do not distinguish forest cover of different ecosystem types (tropical dry forest, cloud forest, rainforests or planted forest; Grantham *et al.* 2020). Adoption of global ecosystem typologies, such as the IUCN ecosystem types (Keith *et al.* 2020) and an increase in data to validate ecosystem maps could resolve this problem improving the use of area-based indicators for monitoring ecosystem integrity (Nicholson *et al.* 2021).

Measures of landscape structure such as connectivity and fragmentation are used for assessing ecosystem integrity but a better understanding is needed for relating the generic measurements with ecosystem processes and functions, such as functional connectivity (Haddad *et al*. 2015; Tucker *et al*. 2018; Nicholson *et al.* 2021).

Species composition indicators are also key for assessing spatial and temporal loss of ecosystem integrity. Assessments of species composition are very sensitive to bias in species data, may lack local or *in-situ* validation, and may need to better assess the impact on species decline or compositional change on ecosystem functions (Nicholson *et al.* 2021). Indices for measuring compositional change such as the Species Habitat Index or Biodiversity Intactness Index use land use change to infer change in species composition; such indicators might be improved by including other drivers such as invasive alien species or the direct exploitation of species (Nicholson *et al.* 2021).

<u>4.3.2.5</u> Monitoring must incorporate local, traditional and indigenous knowledge. Biodiversity monitoring has focused on gathering scientific knowledge but lacks the inclusion of local, traditional and indigenous knowledge, leading to indicators that are biased towards a particular type of understanding of biodiversity. This has been widely recognised including by IPBES and CBD. Local natural resource monitoring remains largely absent from mainstream conservation practice (Danielsen *et al.* 2021).

Inclusion of indigenous and local knowledge can be helped by empowering local communities and building local capacity. Place-based citizen science programs and tools that allow co-design and co-ownership of data provide greater opportunities for such inclusion. Conversely, monitoring programs run by non-local professionals, operating under major time and resource constraints and bound by professional secrecy and territorialism could do much more to include local and indigenous knowledge.

4.3.2.6 Monitoring must involve the collection of long-term data that are accurate, precise and relevant to support not only current GBF indicators but potential future indicators. To the extent that it is possible, this should be based on a value-free approach to measuring biodiversity status (e.g., EBVs). Ecological theory is the foundation of biodiversity indicators. However, indicator selection is a complex process which is influenced by values, policies and legislation of the day and often involves negotiation and trade-offs. For this reason, indicators are expected to change independently from, and faster than, scientific understanding. Hence, a strict coupling of primary data collection with indicators might result in failure to collect data needed for indicators of the future. Ideally monitoring programs designed today, would generate all the data needed to measure the current status of biodiversity in 10, 20, 30 or 40 years' time, using the indicators of that time. Hence global coordination and harmonization on biodiversity monitoring must be guided not only by indicators but also by ecological theory. The EBV concept can help with this because it allows identifying primary data needs for measuring EBVs independently from values of the day and the accepted indicators of the day.

It is important to support and prioritise observation efforts that make the greatest contributions to global biodiversity data, at least cost. This could be critical for getting enough data to support global indicators for the purpose of measuring progress towards 2030 and 2050 targets. It is useful to clearly identify why a given program is efficient and valuable. The great majority of species occurrence records in GBIF are from incidental observations and this proportion is increasing (Chandler *et al.* 2017). Hence it is likely that in the future, incidental (opportunistic) species records will be much more important for tracking change in global biodiversity than species occurrence records generated through systematic monitoring efforts. Recent examples support this. It has been shown that indicators based on unstructured data can provide estimates of change comparable with standardised long-term monitoring data for at least some regions, times, and/or species (Rapacciuolo *et al.* 2021). It has also been shown that the opportunistic data can more efficiently generate estimates of biodiversity status than systematic, rigorous sampling designs. For example an Australia-wide citizen science project, that has been running for ~18 months, was able to predict frog species richness at a continental scale compared with an expert-derived map based on ~240 years of data accumulation (Callaghan *et al.* 2020). Ideally the utility of these programs for measuring global biodiversity should be captured in metadata. One way of doing this is to have a widely accepted typology of monitoring programs to identify the type in the metadata. An alternative is to characterise the programs against a set of criteria without associating them with a type of monitoring program defined *a priori*.

A typology of biodiversity observations that goes beyond the dichotomy of systematic vs. opportunistic can be useful, particularly if it contains specific information about how a particular type of observation can address a specific need to measure a biodiversity variable and how it can complement other observation types. This was demonstrated for primary data supporting distribution and population abundance EBVs by determining the performance of each type against clearly defined criteria (Jetz *et al.* 2019). However even the most detailed typology is unlikely to capture the variation among programs in relation to accuracy, precision and spatial and temporal specificity. An alternative is to define desirable attributes (Table 4.1) and evaluate how each biodiversity monitoring program performs against those criteria. This helps, among other things, to identify the full potential of community-based/locally-based monitoring programs and provide guidance on improving the contribution of such programs to international agreement and goals (Danielsen *et al.* 2014; Chandler *et al.* 2017).

Table 4.1 *How bottom-up (locally-based / community-based) monitoring programs (Danielsen* et al. *2021; Eicken* et al. *2021) can produce data that meet a high-quality standard for each attribute. Data quality in biodiversity monitoring programs with nominal values for the extremes.*

Attribute	Data value		Opportunities offered by locally-based / community-based (bottom-up) biodiversity monitoring
	Poor	Good	
Number of observations*	1	10^5	Large numbers of observers coupled with ample observation opportunities can result in very large datasets.
Spatial grain*	100 km	1m	Local knowledge of survey areas allows observers to fully capture important variations of habitat and landscapes. This becomes particularly important when local and indigenous knowledge is used to search several distinct habitats that are close to one another. Also often in locally based monitoring, observers are able to focus on a single observation at a time, improving the likelihood of accurate and precise recording of the geographic location especially if digital tools are used (Johnson *et al.* 2021). Without very precise recording of the local knowledge it will be lost in monitoring and will not be utilised in model-based inferences because the models (e.g., habitat suitability models) will have a much coarser spatial grain.
Temporal grain*	10 years	<1 Day	The strong connection of observers with the place and their ongoing presence at survey locations, mean that in locally-based monitoring programs observations can potentially be made on any day of the year and any time of the day and over multiple years. This contrasts with many top-down monitoring programs in which a small time window may be used to capture annual patterns.
Temporal scope (duration)	Days	Decades	Locally based programs are typically driven by local interests and passion (Brondízio *et al.* 2021). This makes them relatively immune to the uncertainty associated with short-term funding and political decisions that affect government commitments to biodiversity monitoring.
Spatial scope (extent)*	Site	Globe	Multiple locally-based monitoring programs can collectively deliver data that have a very large spatial scope, especially if there is high level (e.g., national government) commitment to coordinate and support these efforts.
Spatio-temporal representativeness*	Low	High	Local and indigenous knowledge along with continued presence of observers at the place enables capturing observations and time and space combinations that are critical for understanding how and why local biodiversity is changing.

Taxonomic scope*	Small	Large	Local observers have the potential of building knowledge that has a wide taxonomic scope because of the small geographic scope of the program they are involved in. This allows rapid capacity building and learning of multiple taxonomic groups. Locally designed digital tools can provide guidance and learning of just local species and ecosystems and link these with local and indigenous knowledge.
Taxonomic representativeness*	Low	High	The large taxonomic scope of locally-based monitoring programs coupled with local knowledge for a small area allows community monitoring programs to regularly evaluate and improve the taxonomic representativeness of their observations efficiently
Data, metadata sharing*	None	Full	Co-ownership of data and empowerment can effectively remove most barriers to data sharing especially when it is explicitly promoted as a central aspect of the monitoring program.
Data quality control*	Low	High	Co-ownership of data and high level of data sharing at early stages of data curation can ensure high-level scrutiny of data quality.
Abundance inference*	None	Strong	Development of local capacity allows individual observers with interest, skills and capacity to track changes in abundance of local populations at a high temporal grain, especially if they are given appropriate professional guidance and digital tools to easily record their observations.
Format adhering agreed standards*	No	Yes	Higher level of coordination and communication among locally based efforts can help ensure consistency among local programs.
Key metadata included*	No	Yes	The collective nature of locally-based monitoring programs, facilitates compliance with requirements to supply metadata.
Indigenous and local contributions	None	Major	Locally based monitoring programs can maximise local and indigenous contributions at the monitoring design, data collection, quality-control and interpretation stages.
Local capacity building and learning	None	Major	Focus on local species, empowerment, relevance to management and co-ownership of data greatly help observers to learn about local species and ecosystems and develop skills needed to observe these.
Community access to data	Difficult	Easy	Local monitoring programs can empower local communities or their representatives to have early access to locally generated data and review it at all stages of curation. Use of locally designed digital tools to collect and submit data would greatly help with this.

Utility of data for future indicators	Limited	High	Locally-based monitoring is typically not-tied to a specific objective or question, is broad in its taxonomic scope and has high temporal grain. Hence the primary data generated can often support indicators not yet defined, and can be used to address future management questions not yet formulated.
Detection and correction of errors	Low	High	Local ownership of data, allows observers to review and discuss data both before and after submission to databases. The ability of community members or their representative to edit records in databases means that errors can be retrospectively fixed. This also allows development of community knowledge.
Links to management	None	Strong	Monitoring that involves locally-based/ community-based volunteers, experts, and personnel involved in management (e.g., protected area staff) helps to bring management relevance to monitoring and can lead to greater engagement of local communities in conservation action together with relevant personnel.
Cost	High	Low	By integrating biodiversity observations into activities already resourced and accounted for, locally based monitoring programs utilise time and resources that do not require a high level of explicit commitment. The observer's flexibility in using time and space greatly improves the efficiency of monitoring. This can be enhanced by using digital tools that make single observations easy, precise and accurate.

*Attributes described in Jetz *et al* (2019)

Data collected in programs that have the attributes listed above can be extremely useful in tracking biodiversity change even when the cause is unknown, especially if drivers are also quantified either at the time or retrospectively. Such data can often be used to measure multiple EBVs. Because of the high volume and spatial-temporal granularity, precision and accuracy, they can also be used in the future to address many questions and measure many indicators that had not been formulated at the time.

4.3.3 We must monitor drivers to support attribution to the causes of trends and guide action to mitigate their effects

The monitoring of drivers is urgently needed. Biodiversity monitoring has focused on certain measures aimed at detecting change in species presence, abundance, ecosystem and protected areas, but systematic monitoring of drivers is needed to support attribution to the causes of trends and guide action to mitigate their effects. Most attribution of biodiversity trends to drivers is restricted to those drivers that are most easily measured, and over large spatial scales: land cover change, changes in temperature and precipitation (thanks to weather and climate monitoring), direct exploitation for some taxa (e.g., fisheries), and water quality (i.e., measure of nutrient loading, and other pollutants). Other drivers such as pesticides, contaminants, invasive alien species, legal and illegal species trade (e.g., poaching and hunting) are not well monitored (Lenzen *et al.* 2012). The situation in ocean systems is reversed, where a synthesis of certain drivers has been done (Halpern 2020) and in some cases is more practically done over space than direct assessment of biodiversity (Miloslavich *et al.* 2016).

Indirect drivers of biodiversity change have been classed broadly into those related to values, human demographics, technological, economic and governance (IPBES 2019), but their action through direct drivers makes it challenging to assess directly their influence on biodiversity over time and across locations. For example, quantifying biodiversity losses due to human consumption requires assessing multiple indirect and direct drivers, posing significant challenges for data standardization, data mobilization and data access (Wilting et al. 2017). The complexity of these challenges, and the varied data sources that must be accessed, will make it difficult to assess progress with the action targets of the GBF if we do not monitor the links between indirect and direct drivers.

However, there are important synergies that can help resolve this challenge. All direct and indirect drivers result from human activities, and all fall under varied economic, social and/or political institutions. Economic productivity and growth, individual sectors such as agriculture, forestry and fisheries, and social and political sectors such as health, governance and human rights are all domiciled under institutions at multiple levels from national to global (for example, food production and consumption under the UN Food and Agriculture Organization (FAO), transport under the International Maritime Organization (IMO) and the International Air Transport Association (IATA)). Data on these sectors, covering direct and indirect drivers, exist within these complementary institutions to the Convention on Biological Diversity, unified under the United Nations and the Sustainable Development Goals. Operationalizing the GBF as a “framework for all” may tangibly focus on incorporating existing monitoring and reporting structures for key direct and indirect drivers with the monitoring framework of the GBF, without requiring the latter to invest in all of this data compilation. Targeted integration with the SDG monitoring framework, and sectoral monitoring and reporting frameworks should be planned early, to reduce the need for independent monitoring for the GBF.

4.3.4 Monitoring that integrates bottom-up and top-down perspectives is essential to capture the cross-boundary and cross-sectoral nature of biodiversity

Global goals and targets need to be implemented through national and local actions. In order to monitor the relationship between actions, targets and goals, the monitoring framework of the GBF needs to consider the information needed under the different scales where the GBF is implemented, that way biodiversity data obtained from specific monitoring programs can be scaled up to inform global goals.

The integration between information needs and data at the different scales needs to be done both at a bottom-up and top-down perspective (Figure 4.8). However, treating local monitoring efforts as merely local pilots implemented to serve a national or global agenda would not represent a genuine bottom-up approach. Accommodating and encouraging community-driven/ locally driven biodiversity monitoring (Eicken *et al.* 2021) is essential for realising the full benefits of bottom up-monitoring including: utilisation of local and indigenous knowledge; local capacity-building; and longevity of monitoring programs (Table 4.1). Such programs will necessarily emerge out of local needs and dynamics rather than being conceived as pilot projects to support a national agenda. However, in time through various forms of support including co-design, these programs can be aligned with national and global agendas. Top-down interventions to harmonise data through collection and reporting procedures will also be necessary to ensure this alignment (Vaz *et al.* 2021).

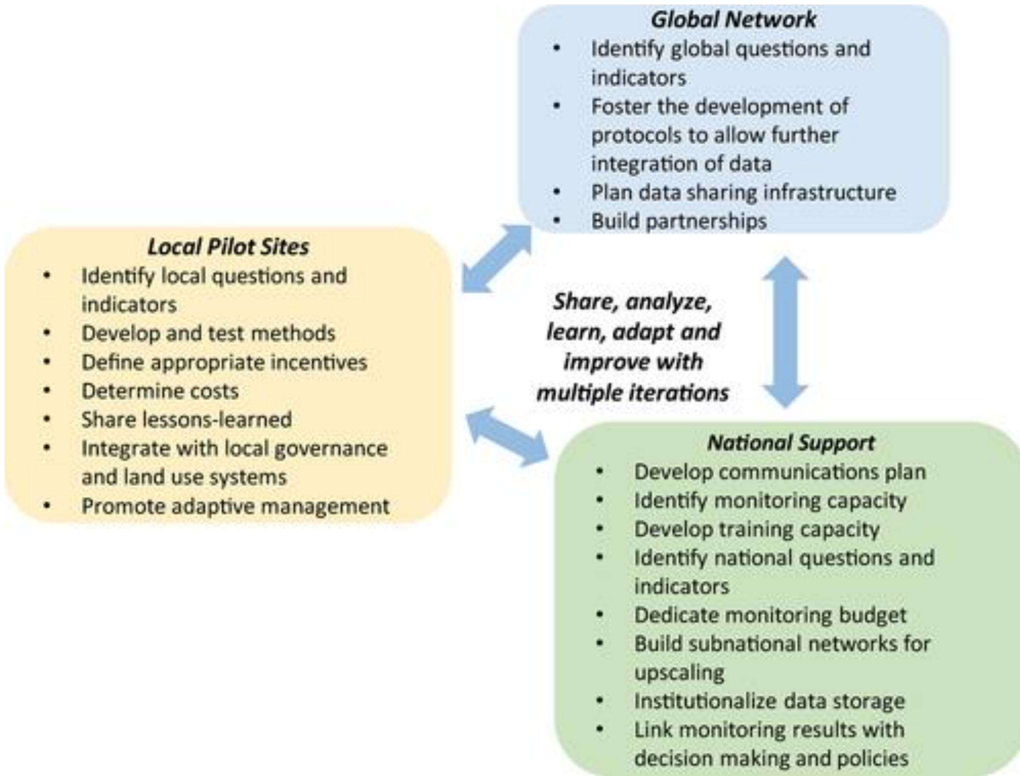


Figure 4.8 *A proposed multilevel approach for researching, planning, and testing a participatory monitoring system for large-scale forest restoration, demonstrating the inherent link between bottom-up (local) and top-down (national and global) interactions (*Source*: Evans* et al. *2018).*

4.3.5 A global biodiversity observation system is needed to support the monitoring framework of the GBF

A global biodiversity observation system (GBiOS), like the global climate observation system, is needed to guide policy and action to meet the goals of the GBF. While there may be as many as 15,000 monitoring schemes worldwide (Moussy *et al.* 2021) these efforts are not harmonised and coordinated to form a global system (Pereira & Cooper 2006; Scholes *et al.* 2012). This situation impedes our understanding of biodiversity change across countries and regions and our ability to assess the success of conservation policy and action worldwide. A GBiOS would form a comprehensive and integrated monitoring system operating from the subnational to the global scale for the purpose of protecting and improving biodiversity. A great deal of biodiversity information is produced by government agencies, research organizations, non-governmental organizations, companies, and civil society groups but it is not coordinated as a global system. Vital sources of information about the changing ecological conditions in land, freshwater, and ocean systems, also exist among indigenous peoples and local communities, which are recognised as important holders of biodiversity knowledge. A GBiOS would coordinate existing monitoring efforts worldwide and interlink groups from indigenous peoples to corporations, civil society, governments and researchers to undertake this work. This major objective will ensure that these groups can contribute, access, and use comprehensive information on the changing state of biodiversity and the impacts of the numerous driving pressures.

A GBiOS would connect to other environmental networks and data from different sectors responsible for drivers to capture trends in drivers to inform a framework that supports detection and attribution of biodiversity change, while also increasing the sensitivity driver indicators. A robust conceptual framework for the relationship between different indicator sets and between indicators and actions should be used to continuously evaluate the process of biodiversity monitoring (Figure 4.1), identify gaps, areas of weakness and setting priorities for subnational to global improvement of monitoring infrastructure and capacity (Hayes *et al.* 2015; Turak *et al.* 2017a). The uptake and utility of such conceptual frameworks will be enhanced greatly if they explicitly integrate societal benefits of improvements in the state of biodiversity and link these to management responses (Sparks *et al.* 2011). Development and use of these conceptual frameworks need to be followed by performance testing, to understand the sensitivity of indicators to change in specific drivers and actions, as well as thresholds that trigger decisions (Jakobsson *et al.* 2021).

4.3.6 Integrative leading indicators are essential to address interlinkages between actions and outcomes during GBF implementation.

Careful setting of quantitative levels for individual goals and targets, informed by best-available science, can go some way towards addressing dependencies between outcomes and actions under the GBF. However, it is likely that a sizable portion of such dependencies will only ever be addressable after these levels have been agreed, and the GBF process proceeds from formulation to implementation. This will particularly be the case for key dependencies between desired outcomes for ecosystems, species and genetic diversity specified under Goal A, and area-based actions (spatial planning, restoration, protection) implemented under Targets 1, 2 and 3.

The role played by indicators in GBF implementation can, and should, extend beyond passive monitoring of national and global progress toward individual targets and goals. Indicators can also play a vital role in informing the prioritization and planning of specific actions which will contribute to addressing shortfalls in achievement of outcomes as efficiently and effectively as possible. Interlinkages between goals and targets are unlikely to be addressed adequately by indicators focused narrowly on measuring progress in relation to each of these components individually, in isolation from the rest of the interlinked system.

This poses a significant challenge for the use of indicators assessing progress against Targets 1, 2 and 3 purely in terms of the extent, or proportional coverage of area-based actions – e.g., the areal percentage of degraded ecosystems subjected to restoration under Target 2. Any individual action can be expected to make at least some contribution to enhancing the overall area, connectivity and integrity of natural ecosystems, with some level of benefit then flowing through, in turn, to improving prospects for retaining species and genetic diversity in accordance with Goal A. The problem is that the magnitude of these benefits is not a simple function of the magnitude of the action itself. This will also depend on the precise location of the action relative to underlying spatial patterns in the distribution of biodiversity (e.g., species' ranges), and on spatial relationships between the area being protected or restored and other areas of natural ecosystems in the surrounding landscape. The net contribution made by actions of a given type will further depend on how the effects of these actions complement, or offset, those of other types of actions and ongoing threatening processes. Failing to account for these interlinkages when prioritising actions to achieve individual targets is likely to reduce the effectiveness and efficiency with which the world can work towards achieving multiple targets and goals under the GBF.

Leading indicators, which predict the impact that proposed or implemented area-based actions are expected to have on the future state of biodiversity, can make an important contribution to addressing this implementation challenge (Stevenson *et al.* 2021). Of particular relevance are various habitat-based biodiversity indicators predicting the level of species diversity expected to be retained, or to persist, within a given spatial reporting unit (e.g., a country, or the entire planet) as a function of the state and configuration of natural ecosystems, or 'habitat', across that unit (Ferrier & Drielsma 2010; UNEP-WCMC 2016). By making simple assumptions regarding how the state of habitat within a specified area will change if a given action (e.g., protection, restoration) is applied to that area, habitat-based indicators offer a straightforward means by which to assess the potential benefit of actions proposed, or implemented, under Targets, 1, 2 and 3 in terms of their expected contribution toward achieving both ecosystem-focused and species-focused outcomes under Goal A. Habitat-based indicators can be derived either through bottom-up aggregation of separate analyses of the availability of suitable habitat for large numbers of individual species, particularly for better-studied biological groups, or through top-down assessment of the expected impact of overall habitat losses and gains on the persistence of species diversity at a whole-community level (Ferrier *et al.* 2017). Most manifestations of this latter community-level approach make use of the species-area relationship, with recent advances in the approach now integrating the effects of changes in ecosystem integrity and connectivity alongside those of ecosystem extent (Ferrier & Drielsma 2010).

The workflow depicted in Figure 4.9 illustrates how an integrative leading indicator might be used to address interlinkages between Goal A and area-based actions under Targets 1, 2 and 3 during GBF implementation.

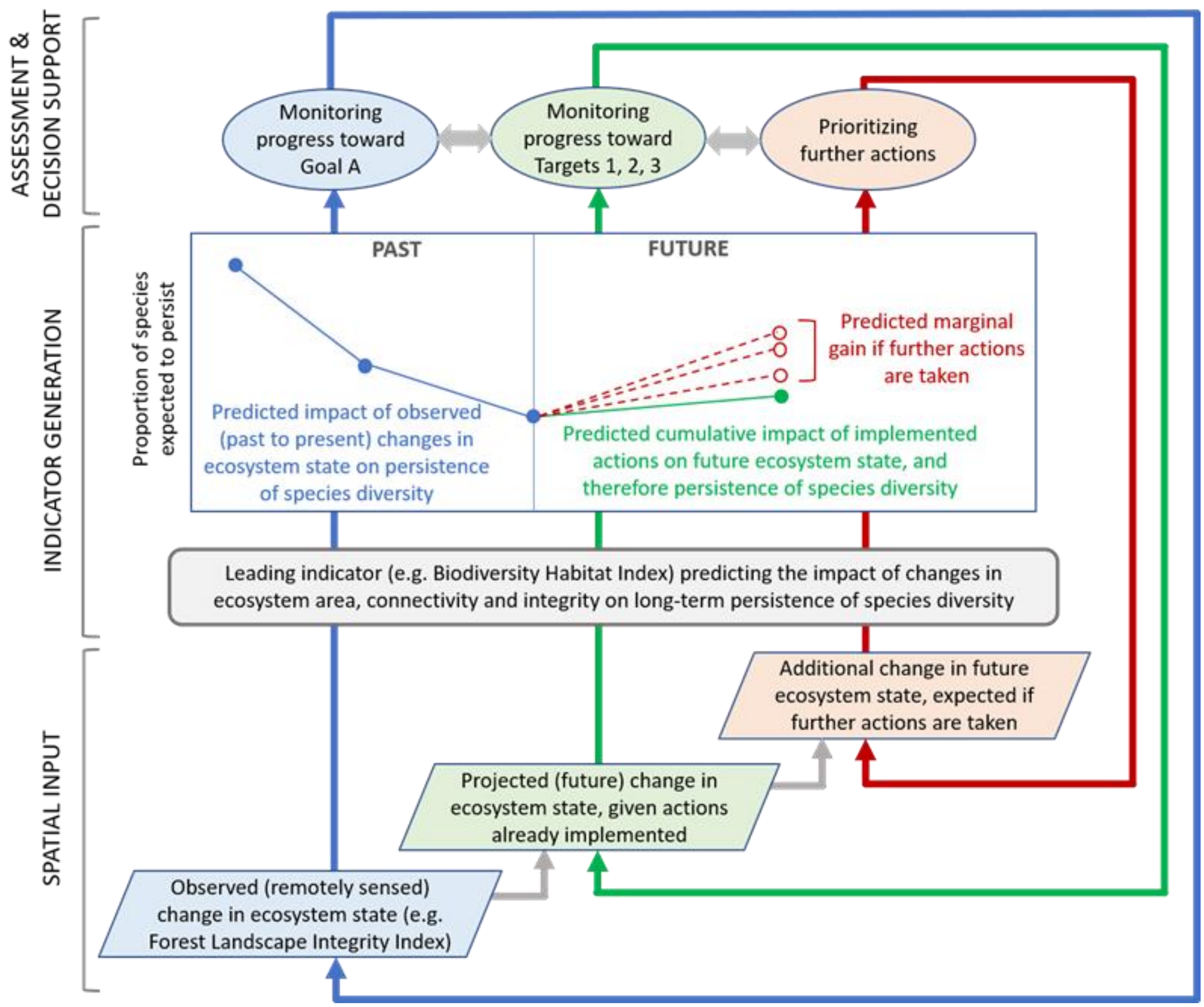


Figure 4.9 *An example of how a leading indicator, in this case the Biodiversity Habitat index (Hoskins* et al. *2020; Hansen* et al. *2021), could be used to integrate monitoring of progress toward Goal A with monitoring and prioritization of area-based actions under Targets 1, 2 and 3.*

This integration would be achieved by employing the same indicator across three major streams of assessment (depicted by the three different colours in Figure 4.9 – blue, green and red):

- *Monitoring progress toward Goal A* would involve predicting change in long-term persistence of species abundances and diversity expected as a function of observed (remotely sensed) change in ecosystem state (extent, connectivity, integrity) using, for example, the Forest Landscape Integrity Index (Grantham *et al.* 2020), thereby addressing the dependency between outcomes for ecosystems and species under this goal.
- *Monitoring progress toward Targets 1, 2 and 3* would involve modifying the current (present day) mapping of ecosystem state to reflect changes which are expected in the future as a result of collective area-based actions (e.g., protection, restoration) already implemented, along with any expected effects of ongoing threats. Then, predicting change in long-term persistence of species diversity using this modified (projected) mapping of ecosystem state, progress against the area-based targets can be expressed in terms of the expected contribution of implemented actions toward achieving outcomes under Goal A.
- *Prioritizing further actions* would involve modifying the above projection of ecosystem state to predict the marginal gain in persistence of species diversity expected if any given additional action, or set of actions, is taken. This can then inform the prioritization of potential actions in terms of their expected contribution to further advancing achievement of Goal A outcomes.

In summary, we have highlighted the fact that the goals, targets, and indicators depend on each other. In this way, the information required to establish whether they are being achieved should be seen as forming a network of information flow supported by an integrated monitoring system. The role played by indicators in the implementation of the GBF can, and should, extend beyond passive monitoring of national and global progress towards individual targets and goals. Indicators can also play a vital role in informing the prioritization and planning of specific actions at both national and global levels. Conservation planning and prioritization informed by monitoring and leading indicators can contribute to addressing shortfalls in the achievement of biodiversity outcomes under the GBF. The combination of indicators with systematic monitoring for detection and attribution of biodiversity change should be seen as an essential element of the overall capacity required to assess progress and proactively guide action to achieving the 2030 milestones and 2050 goals of the GBF.

Technical Section 5: Natural and Managed Ecosystems

5.1 High-level findings for the global biodiversity framework

5.1.1 Reversing biodiversity loss will require addressing threats to biodiversity in both natural and managed ecosystems, as well as the interconnections between them. Natural and managed ecosystems differ in their species and genetic composition, ecosystem functions and supply of ecosystem services, hence the targets for action, reference states, monitoring requirements, and relevant indicators may differ between them.

5.1.2 "Natural ecosystems" are generally defined as ecosystems "whose species composition is predominantly native and determined by the climatic and geophysical environment (see Glossary).

5.1.3 "Managed ecosystems" are those whose biotic composition and functioning is transformed by deliberate manipulation, often to meet specific human needs, such as food production, shelter or even recreation.

5.1.4 Managed ecosystems, especially those managed by indigenous peoples and local communities, play a critical role in biodiversity conservation and there are several ways in which the GBF could better reflect their importance and specificities in the Goals and Targets.

5.1.5 Multifunctional land, freshwater and seascapes, or 'multifunctional -scapes' are increasingly being recognised as key spatial units over which biodiversity conservation actions must integrate with other types of activities.

5.1.6 To better incorporate the contributions of managed ecosystems to achieving the GBF we identify the following opportunities:

- **extend Milestone A.1 to: "Net gain in the area, connectivity and integrity of natural systems of at least 5 per cent, *and in the integrity of managed ecosystems of at least 20 per cent*";**
- **include the term 'integrity' in the text of Target 2 on restoration, where integrity refers to the functionality of an ecosystem and its ecological processes;**

- **include relevant indicators in the monitoring framework in relation to integrity of natural ecosystems, managed ecosystems, and restoration reference points and targets relevant to each;**
- **apply emerging guidance for 20% of land and sea area in managed ecosystems to be under 'intact native habitat' (i.e., 20% 'natural' in the mosaic of multifunctional scapes) to facilitate integrated implementation of targets and actions in locally appropriate ways.**

5.2 Plain-language summary

"Natural ecosystems" are generally defined as ecosystems "whose species composition is predominantly native and determined by the climatic and geophysical environment" (see Glossary). This does not mean natural ecosystems are devoid of human influence; now, none are exempt from climate change impacts. Indeed, the majority of "natural" ecosystems have been reconfigured by people to a significant extent (Ellis *et al.* 2021), although not to a degree that is so dominated by human needs as to qualify as "managed" ecosystems.

"Managed ecosystems" are those whose biotic composition and functioning is more heavily transformed by deliberate manipulation, often to meet specific human needs, such as food production, shelter or even recreation. Managed ecosystems may include built-up areas, cropland, pastures (but not rangeland with low animal density), tree plantations, aquaculture and reservoirs. The term "converted ecosystems" is sometimes used, and may refer to natural ecosystems that have been converted to managed ecosystems.

"Natural" and "managed" ecosystems co-occur in complex mosaics where people live close to and interact with biodiversity, and where ecological functions may be transformed towards optimizing provisioning of benefits to people. Ecosystems can be classified along a gradient of human impacts from large areas that are largely free from human influence other than climate change (often referred to as "wilderness" on land) to intensively managed or altered ecosystems such as croplands, areas under aquaculture, reservoirs, etc.

Retaining and restoring natural ecosystems is a top priority for "bending the curve" for biodiversity because of the role that ecosystems have in hosting all dimensions of biodiversity. Managed ecosystems also play a critical role in biodiversity conservation. Many managed ecosystems have a very long history of extensive management and integration of indigenous peoples and local communities with nature. Such managed ecosystems may have high habitat and species conservation priorities in their own right. Further, managed ecosystems may provide habitat for many species that can make use of both natural and managed ecosystems (such as insect pollinators), and importantly, managed ecosystems may provide connectivity between natural ecosystems; these features contribute to the ecological integrity of managed ecosystems.

5.3 Statements summarising the evidence

5.3.1 Natural and managed ecosystems differ in their species and genetic composition, ecosystem functions and supply of benefits to people.

Ecosystems can be classified along a gradient of human impacts from large areas that are largely free from human influence other than climate change (often referred to as "wilderness" on land) to intensively managed or altered ecosystems such as croplands, areas under aquaculture, reservoirs, etc. (IPBES 2019; Locke *et al.* 2021). This finding reiterates and expands on recommendations in CBD/SBSTTA/24/INF/9 (see also Díaz *et al.* 2020).

5.3.2 "Natural ecosystems" are generally defined as ecosystems "whose species composition is predominantly native and determined by the climatic and geophysical environment" (see Glossary).

This does not mean they are devoid of human influence, and we know that now none are exempt from climate change impacts. Indeed, the majority of "natural" ecosystems have been reconfigured by people to a significant extent, although not to a degree that is so dominated by human needs as to qualify as "managed" ecosystems.

Estimates of the fraction of land that can still be viewed as "natural" rather than anthropogenic range from under 25% (Ellis & Ramankutty 2008) to over 50% (Sayre *et al.* 2017), depending on how "natural" is defined. Just 39% of land area is still classed as primary vegetation (i.e., has never been cleared or regularly grazed; Ellis *et al.* 2010; Hurtt *et al.* 2020). Ellis *et al.* (2010) estimated that by 2000, the majority of land area was agricultural and settled anthromes, with less than 20% semi-natural and only a quarter in large wild areas. Locke *et al.* (2019) estimated that large wild areas constitute 27% of land area (but included some ice-covered land like Greenland). In the ocean, while human traces can be detected over more than 95% of its area (Halpern *et al.* 2008), two thirds (65%) were showing increasing cumulative human impacts as of 2015 (Halpern *et al.* 2015; IPBES 2019). Nearshore coastal ecosystems show greater exposure to human activity and correspondingly low proportions of being in a natural state, such as mangroves.

5.3.3 "Managed ecosystems" are those whose biotic composition and functioning is transformed by deliberate manipulation, often to meet specific human needs, such as food production, shelter or even recreation (IPBES 2019).

Managed ecosystems may include built-up areas, cropland, pastures (but not rangeland with low animal density), tree plantations, aquaculture and reservoirs (Ellis 2019). Other terms with broadly similar intent include "converted ecosystems" and “working lands” (e.g., Kremen & Merenlender 2018; Deichmann *et al.* 2019) and including seascapes. The term “converted ecosystems” may refer to natural ecosystems that have been converted to managed ecosystems. Conversion often leads to large changes in species composition, ecosystem function and ecosystem services, but converted ecosystems may or may not be considered as degraded if their functionality remains high in some aspects.

5.3.4 Retaining and restoring natural ecosystems is a top priority for "bending the curve" for biodiversity because of the role that ecosystems have in hosting all dimensions of biodiversity.

The importance of contributions of natural ecosystems to Goal A is well reflected in the GBF, citing area, connectivity and integrity (see Glossary for terms) as critical elements of ecosystems in Goal A (CBD/SBSTTA/24/INF/9; see also Díaz *et al.* 2020), and for which indicators may be cascaded into Milestones and then to Targets (see Section 4). With many ecosystems already below a threshold of area loss and integrity there are a number of critical ecosystems for which zero further loss is necessary to avoid further biodiversity loss (Díaz *et al.* 2020). Weak application of the No Net Loss principle can drive the loss of critical ecosystems through substitution of lower quality ecosystems for higher ones, compounded by inappropriate discounting of the lag effects for full recovery (see Section 2).

5.3.5 Managed systems play a critical role in biodiversity conservation.

Many managed ecosystems have a very long history of extensive management and integration of indigenous peoples and local communities with nature, such as Cultural Landscapes recognised by the World Heritage Convention, Globally Important Agricultural Heritage Systems (GIAHS) by the FAO and Satoyama Initiative societies designed around living in harmony with nature (Pörtner *et al.* 2021). Such managed ecosystems may have high habitat and species conservation priorities in their own right. Further, managed ecosystems may provide habitat for many species that can make use of both natural and managed ecosystems (such as insect pollinators), and importantly, managed ecosystems may provide connectivity between natural ecosystems (Mitchell *et al.* 2013; Boscolo *et al.* 2017; Senapathi *et al.* 2017); these features contribute to the ecological integrity of managed ecosystems (see also Section 1.3.7.3).

To better incorporate the contributions of managed ecosystems to Goal A (as well as Goals B and C), extending Milestone A.1 can help: "Net gain in the area, connectivity and integrity of natural systems of at least 5 per cent, *and in the integrity of managed ecosystems of at least XX per cent*".

Recent literature supports a figure of 20% of landscapes to be under intact, natural vegetation to sustain biodiversity and supply benefits to people (Díaz *et al.* 2020; Garibaldi *et al.* 2021), so this figure is proposed.

5.3.6 Multifunctional land, freshwater and seascapes, or 'multifunctional -scapes' are increasingly being recognised as key spatial units over which biodiversity conservation actions must integrate with other types of activities, such as around climate change, agriculture, energy production, etc.

Multifunctional 'scapes contain complex spatial patterning of natural and managed ecosystems, and fully transformed spaces such as cities (Figure 5). The inter-connectedness of natural and managed ecosystems in these 'scapes may allow for the mutually supportive integration of ecological functions and services, such as managed/restored habitats providing connectivity between natural ecosystem patches, natural/restored ecosystems providing habitat for pollinators of agricultural crops, etc. Emerging guidance for 20% of area to be under 'intact native habitat' (Garibaldi *et al.* 2021) can be used as explicit guidance to deliver GBF targets in an integrated and locally appropriate way (which is implicit in meeting Target 21 concurrently; Obura *et al.* 2021), to inform how individual locations or countries might contribute towards achieving the global goals.

5.3.7 Biodiversity, ecosystem functioning and ecosystem resilience contribute differently to ecosystem integrity in managed and natural ecosystems, and thus targets for action, reference states, monitoring requirements, and relevant indicators may differ between them.

In a natural ecosystem, a target state may be determined by a historical reference state and its native biota, while accommodating expected change due to climate change. Degraded natural ecosystems and some managed ecosystems may be restored to this target state. However, in some degraded or managed ecosystems it may be impossible, or not desirable, to return towards a native state, and a new state may be targeted based on the supply of ecosystem function and/or services.

The GBF should target an increase in both area and integrity of natural ecosystems (CBD/SBSTTA/24/INF/9; Diaz *et al*. 2020). But it can only target an increase in the integrity of managed ecosystems, as their area must necessarily decline as the area of natural ecosystems is increased. Additionally, there is a difference between restoring degraded/managed ecosystems to natural ecosystems vs. to a managed ecosystem with higher integrity (e.g., for greater functions such as in supporting connectivity, pollination and other services for adjacent farmland).

This difference between integrity in natural and managed ecosystems can be supported in the GBF text by the reference to managed ecosystem integrity in Milestone A.1 (and Goal A) and with inclusion of the term ‘integrity’ in the text of Target 2 on restoration, thus facilitating inclusion of relevant indicators in the monitoring framework in relation to natural ecosystems, managed ecosystems, and restoration targets relevant to each.

Operationalizing these differences between natural and managed ecosystems within local contexts, and establishing appropriate monitoring, will require further work during implementation of the GBF.

Abbreviations

BMSY: biomass maximum sustainable yield

CARE: collective benefit, authority to control, responsibility and ethics

CBD: Convention on Biological Diversity

DPSIR: driver, pressures, state, impact and response

EBVs: essential biodiversity variables

FAIR: findable, accessible, interoperable and reusable

FAO: Food and Agriculture Organization of the United Nations

GBF: global biodiversity framework

GBIF: Global Biodiversity Information Facility

GBiOS: Global Biodiversity Observation System

GEO BON: Group on Earth Observations Biodiversity Observation Network

GIAHS: Globally Important Agricultural Heritage Systems

GOOS: Global Ocean Observing System

IAS: invasive alien species

IPBES: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

IPLCs: indigenous peoples and local communities

IPPC: Intergovernmental Panel on Climate Change

IUCN: International Union for Conservation of Nature

IUCN EICAT: International Union for Conservation of Nature Environmental Impact Classification for Alien Taxa

MPAs: marine protected areas

NCP: nature's contributions to people

OBIS: Ocean Biodiversity Information System

OECMs: other effective area-based conservation measures

OEWG: Open-ended Working Group

PAs: protected areas

PSBR: pressure, state, benefit, response

RCP: Representative Concentration Pathway

SDGs: Sustainable Development Goals

SSP: Shared Socio-economic Pathways

TDWG: Taxonomic Databases Working Group, now referred to as Biodiversity Information Standards (TDWG)

ToC: Theory of Change

UNOOSA: United Nations Office for Outer Space Affairs

UN SEEA-EA: United Nations System of Environmental Economic Accounting - Ecosystem Accounting

Glossary

The following glossary is provided as a complement to CBD/WG2020/3/3/Add.2/Rev.1[7]. Terms used in this document and CBD documents follow the definition provided by the CBD. We have added terms related to drivers and their effects.

Term	**Definition**	**Source**
Attribution	The process of evaluating the relative contributions of causal factors to a measure of biodiversity change with statistical estimates of confidence. The attribution of a driver, or set of drivers, to the detected change in biodiversity measures, is based on a causal model. Alternative models are compared to attain the strongest inference about the underlying causes of the change.	
Baseline	A fixed reference point that is used for the purpose of comparison.	Monitoring framework[8,9]
Baseline condition	A reference point for the ecological, economic or social condition describing the state of the system in question. The baseline condition may be associated with a historical state in the past, or a contemporary state observed in a relevant geographic location.	Monitoring framework
Bending the curve	Pathways to halting and reversing the loss of biodiversity. Depending on the social and economic scenario there are many possible pathways leading to action on indirect and direct drivers that may reverse the loss of biodiversity. Each pathway may vary in the rate of change and degree of recovery in the coming decades.	van Vuuren *et al*. 2017; Mace *et al.* 2018; Leclère *et al.* 2020

[7] CBD/WG2020/3/3/Add.2/Rev.1 Glossary for the First Draft of the Post-2020 Global Biodiversity Framework, version dated 26 November 2021.
[8] CBD/WG2020/3/3/Add.1 Proposed Headline Indicators of the Monitoring Framework for the Post-2020 Global Biodiversity Framework
[9] CBD/SBSTTA/24/INF/16 Indicators for the Post-2020 Global Biodiversity Framework

Biodiversity dimensions	Refers to different dimensions of biological diversity including genetic, trait, population, species, community and ecosystems. Biological diversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. (article 2 of the convention, https://www.cbd.int/convention/articles/?a=cbd-02)	
Biodiversity indicator	Two definitions are relevant: 1. A quantitative or qualitative variable that provides reliable means to measure a particular phenomenon or attribute of biodiversity. 2. A quantitative or qualitative variable that provides a simple and reliable way to measure the state of biodiversity, assess progress to a conservation objective, or to help assess the performance of a policy derived action for biodiversity.	Noss 1990; Walpole *et al.* 2017; McQuatters-Gollop *et al*. 2019
Climate debt	Any future biodiversity change that species/ecosystems will incur due to climate change but which has yet to be realized because of time delays in species extinction and colonization.	Devictor *et al.* 2012
Converted ecosystem	May be used to indicate conversion of a natural ecosystem to another state. Has equivalence to the term ‘managed ecosystem’	Díaz *et al.* 2020

Degraded ecosystem	Land degradation can occur either through a loss of biodiversity, ecosystem functions or services. From an ecological perspective, land degradation may include complete transformation in the class or use of the ecosystem, such as the conversion of natural grassland to a crop field, delivering a different spectrum of benefits, but also degradation of the "natural" or "transformed" system. Natural ecosystems are often degraded prior to being transformed. The transformed ecosystem that results from this conversion can, in turn, be degraded and see a reduction in the delivery of its new functions (e.g., an agricultural field where soil degradation and reduced soil fertility leads to reduced crops). The same concepts are applicable to the degradation of marine and freshwater ecosystems. It may take the form of changed trophic structures in a marine community (through fishing pressure and selective removal of species, transformation of the soft and hard benthos (through repetitive sweeps of contacting gears, such as trawls) or artificial reef construction, to cite only a few examples). In the case of aquatic freshwater ecosystems, the construction of dams and reservoirs over river courses or the conversion of natural wetlands into rice paddies are examples of ecosystem transformation.	CBD/WG2020/3/3/Add.2/Rev.1 CBD/POST2020/WS/2019/11/3
Direct driver	Events or processes (natural and anthropogenic) that unequivocally influence biodiversity and ecosystem states and processes. Drivers, both non-human-induced and anthropogenic, affect nature directly. Direct anthropogenic drivers are those that flow from human institutions and governance systems and other	IPBES 2019 (Chapter 1 and 2)

	indirect drivers. Five main direct drivers are commonly assessed: land/sea use change, climate change, direct exploitation, invasive alien species and pollution.	
DPSIR	The Driving Forces–Pressures–State–Impacts–Responses (DPSIR) framework	European Commission, Eurostat 1999
Ecosystem approach	The ecosystem approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. Application of the ecosystem approach will help to reach a balance of the three objectives of the Convention. It is based on the application of appropriate scientific methodologies focused on levels of biological organization which encompass the essential processes, functions and interactions among organisms and their environment. It recognizes that humans, with their cultural diversity, are an integral component of ecosystems.	CBD (decision V/6)[10]
Ecosystem integrity	The continuity and full character of a complex system, including its ability to perform all the essential functions throughout its geographic setting; the integrity concept within a managed system implies maintaining key components and processes throughout time. Ecosystem 'integrity' is generally used to refer to the completeness and functionality of an ecosystem. When we use the term ecosystem integrity we refer to the compositional completeness and functionality of an ecosystem and its ecological processes, particularly in relation to its	IUCN[11]

[10] COP 5 decision V/6 Ecosystem approach
[11] https://www.iucn.org/sites/dev/files/iucn-glossary-of-definitions_en_2021.05.pdf

	natural state.	
Essential biodiversity variables	These are derived measurements required to study, report and manage biodiversity change, focusing on status and trend in elements of biodiversity. There are six classes (genetic, species traits, species population, community composition, ecosystem structure, and ecosystem function) and 20 distinct EBVs.	Pereira *et al.* 2013
Extinction debt	Any future biodiversity loss that will be incurred by current or past habitat destruction or disturbance but which have yet to be realized because of time delays in extinction.	Tilman *et al.* 1994; Hanski & Ovaskainen 2002; Figueiredo *et al.* 2019
Immigration credit	The number of species committed to eventual immigration following a forcing event.	Jackson & Sax 2010
Impact	Refer to effects on living beings and non-living compartments of ecosystems (aquatic, terrestrial and atmospheric). These changes are often construed as “negative”, in the sense that they affect adversely the functioning of ecosystems relative to their potential performance, under otherwise plausible conditions	Maxim *et al.* 2009
Indirect driver	Underlying causes of the magnitude of a direct driver. Indirect drivers alter the level or rate of change of one or more direct drivers. Human actions and decisions that affect nature diffusely by altering and influencing direct drivers as well as other indirect drivers. They do not physically impact nature or its contributions to people. Indirect drivers include economic, demographic, governance, technological and cultural ones, among others.	IPBES 2019 (Chapter 1 and 2)
Intactness	Intactness has two dimensions: 1) it is a measure of the composition and abundance of native species and their	Beyer *et al.* 2020; Plumptre *et al*. 2021

	interactions; 2) a measure of the degree to which the structure of habitat has been changed due to human disturbance; this is often measured by loss of habitat area and quality and an increase in fragmentation.	
Leading indicator	An indicator that informs and predicts the impact of implemented or proposed actions on the current and future state of biodiversity. Leading indicators should change before the subject of interest, thus informing preventative actions.	Stevenson *et al.* 2021
Managed ecosystem	Are those whose biotic composition is the result of deliberate manipulation by people, this often being a stronger factor than climate or substrate. In many cases the main plant or animal assemblages are designed anew for the purposes of serving human ends, such as providing food, fibers, energy or recreation.	Díaz *et al*. 2020
Monitoring	The process of gathering information about essential biodiversity variable(s) at different points in time for the purpose of assessing system state and drawing inferences about changes in state over time. An additional step in monitoring may include estimating and reporting an indicator: the process that includes collection of primary biodiversity data, synthesis of data into an indicator, and public dissemination of trends in the indicator.	Yoccoz *et al*. 2001 Jones *et al.* 2011
Natural ecosystem	Areas composed of viable assemblages of plant and/or animal species of largely native origin and/or where human activity had not essentially modified an area's primary ecological functions and species composition.	CBD/WG2020/3/3/Add.2/Rev.1 see also Díaz *et al.* 2020

Nature-based solutions	Actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits. They are underpinned by benefits that flow from healthy ecosystems and target major challenges like climate change, disaster risk reduction, food and water security, health and are critical to economic development.	IUCN[12]
Rate of extinction	The number of species that become extinct in a given period of time.	CBD/WG2020/3/3/Add.2/Rev.1
Reference reporting period	The time period used as the starting point for reporting progress on targets and goals	Monitoring framework
Restoration (ecological)	Any intentional activity that initiates or accelerates the recovery of an ecosystem from a degraded state. An additional recent definition adds human values: ecological restoration is the process of assisting the recovery of degraded ecosystems to provide goods and services that people value. Refers to the process of managing or assisting the recovery of an ecosystem that has been degraded, damaged or destroyed as a means of sustaining ecosystem resilience and conserving biodiversity	IPBES 2019 Martin 2017 CBD/COP/DEC/XIII/5
Restoration debt	The loss of biodiversity and ecosystem functioning during the ecosystem recovery process, following a disturbance. Ecosystem recovery can be either human-induced or natural.	Moreno-Mateos *et al*. 2017
Risk of extinction	The probability that a species will go extinct in a given period of time.	CBD/WG2020/3/3/Add.2/Rev.1

[12] https://www.iucn.org/theme/nature-based-solutions/about

Shifting baseline	Is a type of change to how a system is measured, usually against previous reference points (baselines), which themselves may represent significant changes from an even earlier state of the system. The loss of knowledge about previous states of the natural world because changes that are taking place are not perceived and recorded.	
Shifting baseline syndrome	Describes a gradual change in the accepted norms for the condition of the natural environment due to lack of past information or lack of experience of past conditions. This results in an increased tolerance for progressive environmental degradation, changes in people's expectations as to what is a desirable state of the natural environment (i.e., one that is worth protecting), and the establishment and use of inappropriate baselines for nature conservation, restoration and management	Soga & Gaston 2018
Telecoupling	Refers to socioeconomic and environmental interactions between distant coupled human and natural systems. It incorporates more conventional components of connectivity in biological realms.	Liu *et al*. 2013; Hull & Liu 2018
Transformative change	A fundamental, system-wide reorganization across technological, economic and social factors, including paradigms, goals and values.	IPBES 2019

Appendices

Appendix 1.0 Goals, Milestones and Targets of the Post-2020 Global Biodiversity Framework[13]

2050 Vision

The vision of the framework is a world of living in harmony with nature where: "By 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people."

2030 Mission

The mission of the framework for the period up to 2030, towards the 2050 vision is: "To take urgent action across society to conserve and sustainably use biodiversity and ensure the fair and equitable sharing of benefits from the use of genetics resources, to put biodiversity on a path to recovery by 2030 for the benefit of planet and people."

2050 Goals and 2030 Milestones

The framework has four long-term goals for 2050 related to the 2050 Vision for Biodiversity. Each 2050 goal has a number of corresponding milestones to assess, in 2030, progress towards the 2050 goals.

The four goals and their associated milestones are:

Goal A. The integrity of all ecosystems is enhanced, with an increase of at least 15 per cent in the area, connectivity and integrity of natural ecosystems, supporting healthy and resilient populations of all species, the rate of extinctions has been reduced at least tenfold, and the risk of species extinctions across all taxonomic and functional groups, is halved, and genetic diversity of wild and domesticated species is safeguarded, with at least 90 percent of genetic diversity within all species maintained.

> Milestone A.1
> Net gain in the area, connectivity and integrity of natural systems of at least 5 per cent.
>
> Milestone A.2
> The increase in the extinction rate is halted or reversed, and the extinction risk is reduced by at least 10 per cent, with a decrease in the proportion of species that are threatened, and the abundance and distribution of populations of species is enhanced or at least maintained.
>
> Milestone A.3
> Genetic diversity of wild and domesticated species is safeguarded, with an increase in the proportion of species that have at least 90 per cent of their genetic diversity maintained.

[13] CBD 2021: First Draft of the post-2020 Global Biodiversity Framework. CBD/WG2020/3/3, issued 5 July 2021. https://www.cbd.int/doc/c/914a/eca3/24ad42235033f031badf61b1/wg2020-03-03-en.pdf

Goal B. Nature's contributions to people are valued, maintained or enhanced through conservation and sustainable use supporting the global development agenda for the benefit of all.

Milestone B.1
Nature and its contributions to people are fully accounted and inform all relevant public and private decisions.

Milestone B.2
The long-term sustainability of all categories of nature's contributions to people is ensured, with those currently in decline restored, contributing to each of the relevant Sustainable Development Goals.

Goal C. The benefits from the utilization of genetic resources are shared fairly and equitably, with a substantial increase in both monetary and non-monetary benefits shared, including for the conservation and sustainable use of biodiversity.

Milestone C.1
The share of monetary benefits received by providers, including holders of traditional knowledge, has increased.

Milestone C.2
Non-monetary benefits, such as the participation of providers, including holders of traditional knowledge, in research and development, has increased.

Goal D. The gap between available financial and other means of implementation, and those necessary to achieve the 2050 Vision, is closed.

Milestone D.1
Adequate financial resources to implement the framework are available and deployed, progressively closing the financing gap up to at least US $700 billion per year by 2030.

Milestone D.2
Adequate other means, including capacity-building and development, technical and scientific cooperation and technology transfer to implement the framework to 2030 are available and deployed.

Milestone D.3
Adequate financial and other resources for the period 2030 to 2040 are planned or committed by 2030.

2030 Action Targets

The framework has 21 action-oriented targets for urgent action over the decade to 2030. The actions set out in each target need to be initiated immediately and completed by 2030. Together, the results will enable achievement of the 2030 milestones and of the outcome-oriented goals for 2050. Actions to reach these targets should be implemented consistently and in harmony with the Convention on Biological Diversity and its Protocols and other relevant international obligations, taking into account national socioeconomic conditions.

1. *Reducing threats to biodiversity*

Target 1. Ensure that all land and sea areas globally are under integrated biodiversity-inclusive spatial planning addressing land- and sea-use change, retaining existing intact and wilderness areas.

Target 2. Ensure that at least 20 percent of degraded freshwater, marine and terrestrial ecosystems are under restoration, ensuring connectivity among them and focusing on priority ecosystems.

Target 3. Ensure that at least 30 per cent globally of land areas and of sea areas, especially areas of particular importance for biodiversity and its contributions to people, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.

Target 4. Ensure active management actions to enable the recovery and conservation of species and the genetic diversity of wild and domesticated species, including through *ex-situ* conservation, and effectively manage human-wildlife interactions to avoid or reduce human-wildlife conflict.

Target 5. Ensure that the harvesting, trade and use of wild species is sustainable, legal, and safe for human health.

Target 6. Manage pathways for the introduction of invasive alien species, preventing, or reducing their rate of introduction and establishment by at least 50 per cent, and control or eradicate invasive alien species to eliminate or reduce their impacts, focusing on priority species and priority sites.

Target 7. Reduce pollution from all sources to levels that are not harmful to biodiversity and ecosystem functions and human health, including by reducing nutrients lost to the environment by at least half, and pesticides by at least two thirds and eliminating the discharge of plastic waste.

2. *Meeting people's needs through sustainable use and benefit-sharing*

Target 9. Ensure benefits, including nutrition, food security, medicines, and livelihoods for people especially for the most vulnerable through sustainable management of wild terrestrial, freshwater and marine species and protecting customary sustainable use by indigenous peoples and local communities.

Target 10. Ensure all areas under agriculture, aquaculture and forestry are managed sustainably, in particular through the conservation and sustainable use of biodiversity, increasing the productivity and resilience of these production systems.

Target 11. Maintain and enhance nature's contributions to regulation of air quality, quality and quantity of water, and protection from hazards and extreme events for all people.

Target 12. Increase the area of, access to, and benefits from green and blue spaces, for human health and well-being in urban areas and other densely populated areas.

Target 13. Implement measures at global level and in all countries to facilitate access to genetic resources and to ensure the fair and equitable sharing of benefits arising from the use of genetic resources, and as relevant, of associated traditional knowledge, including through mutually agreed terms and prior and informed consent.

3. *Tools and solutions for implementation and mainstreaming*

Target 14. Fully integrate biodiversity values into policies, regulations, planning, development processes, poverty reduction strategies, accounts, and assessments of environmental impacts at all levels of government and across all sectors of the economy, ensuring that all activities and financial flows are aligned with biodiversity values.

Target 15. All businesses (public and private, large, medium and small) assess and report on their dependencies and impacts on biodiversity, from local to global, and progressively reduce negative impacts, by at least half and increase positive impacts, reducing biodiversity-related risks to businesses and moving towards the full sustainability of extraction and production practices, sourcing and supply chains, and use and disposal.

Target 16. Ensure that people are encouraged and enabled to make responsible choices and have access to relevant information and alternatives, taking into account cultural preferences, to reduce by at least half the waste and, where relevant the overconsumption, of food and other materials.

Target 17. Establish, strengthen capacity for, and implement measures in all countries to prevent, manage or control potential adverse impacts of biotechnology on biodiversity and human health, reducing the risk of these impacts.

Target 18. Redirect, repurpose, reform or eliminate incentives harmful for biodiversity, in a just and equitable way, reducing them by at least US$ 500 billion per year, including all of the most harmful subsidies, and ensure that incentives, including public and private economic and regulatory incentives, are either positive or neutral for biodiversity.

Target 19. Increase financial resources from all sources to at least US$ 200 billion per year, including new, additional and effective financial resources, increasing by at least US$ 10 billion per year international financial flows to developing countries, leveraging private finance, and increasing domestic resource mobilization, taking into account national biodiversity finance planning, and strengthen capacity-building and technology transfer and scientific cooperation, to meet the needs for implementation, commensurate with the ambition of the goals and targets of the framework.

Target 20. Ensure that relevant knowledge, including the traditional knowledge, innovations and practices of indigenous peoples and local communities with their free, prior, and informed consent, guides decision-making for the effective management of biodiversity, enabling monitoring, and by promoting awareness, education and research.

Target 21. Ensure equitable and effective participation in decision-making related to biodiversity by indigenous peoples and local communities, and respect their rights over lands, territories and resources, as well as by women and girls, and youth.

Appendix 1.1 Quantification of target-milestone interactions for Figure 2

This section justifies the quantification of target - milestone interactions used in the Executive Summary paragraph 1 and Figure 2, and the more detailed network diagram in Section 1.3.1, Figure 1.1 (and see Appendix 1.2). The 21 action targets in the GBF correspond roughly to direct and indirect drivers and to nature's contributions to people as classified by IPBES (2019), as well as tools and solutions for delivering the GBF (Table A1.1). However this is a coarse mapping based on interpretation of the text of the targets and milestones, and the biological relationships that underpin them, contributing to the many-to-many relationships among the targets and to the outcomes. For example, Target 1 explicitly cites addressing land and sea use change and retaining intact ecosystems thus implying an ecosystem focus, but spatial planning also provides the framework for implementation and integration of all action targets together. Finally, IPBES assigned a greater impact of land and sea use change on species dimensions of biodiversity than on ecosystem dimensions (see Figure 1.4 and quantification in Tables A1.2 and A1.3), such that while Target 1 may be seen as specifically relating to land and sea use change, the driver it addresses impacts more on species (Milestone A.2) than ecosystem (Milestone A.1) outcomes.

Table A1.1 *The 21 action targets of the GBF correspond roughly to direct and indirect drivers, nature's contributions to people and means of implementation.*

Direct drivers	**Indirect drivers*, tools and solutions**
Land and sea use change - T1/2/3 Direct exploitation of organisms, species conservation - T4/5 Invasive alien species - T6 Pollution - T7 Climate change - T8	Mainstreaming biodiversity - T14 Sustainable production - T15 Sustainable consumption - T16 Biotechnology - T17 Harmful incentives - T18 Financial resources - T19 Knowledge and capacities - T20 Participation and inclusion - T21
Nature's Contributions to People	
Access and benefits to all - T9 Direct exploitation (agriculture, aquaculture, forestry) - T10 Regulation/hazards/extreme events - T11 Urban green/blue spaces - T12 Genetic resources, ABS - T13	

** The four broad classes of indirect drivers identified by IPBES (2019) are summarised as demographic and sociocultural, economic and technological, institutions and governance, and conflicts and epidemics.*

To illustrate the relationships of each target to delivering the milestones of the GBF, Figure 2 was developed using two sources of information: a) the attribution of direct drivers of biodiversity decline to components of biodiversity, as shown in Figure 1.3, and b) for those targets not covered by this (Targets 9 and 10), expert judgement. The decisions are documented below and in Tables A1.2 and A1.3. The approach used by IPBES (2019, Section 2.2.6), was based on reviews of the scientific literature and on attribution by IPLCs to assign weightings of drivers to components of biodiversity at a global level, among four world regions and major realms. This approach has limitations, and weightings may be quite different especially for smaller scales and specific systems.

The relative contribution of each direct driver to the decline in elements of biodiversity was scaled to add up to a total of 10 (Table A1.2), the average contribution for each of the three milestone elements of biodiversity (i.e., ecosystems, species, genes, as shown in Figure 3) was calculated, then the total attributed to 'other' causes of decline was assigned evenly across the direct drivers (assuming equal interactions across them). Reordered and transposed to match the order of targets and milestone elements gives the scores in Table A1.3, which also documents additional assumptions made for Targets 9 and 10 that could not be assigned weights in the same way. The assumptions about targets addressing different direct drivers, and between-target interactions are mirrored in Figure 1.1 (and see Appendix 1.2).

Table A1.2 *Relative contribution of each direct driver to decline in dimensions of biodiversity, on a baseline scale of zero to 10 (Source: IPBES 2019, Section 2.2.6 - as shown in Figure 3). A) individual contributions read from Figure 3, B) aggregate contributions for the three components of biodiversity, with the value for 'other' added uniformly across the five direct drivers. CC - climate change; Exp- direct exploitation of organisms; IAS - invasive alien species; LSUC - land and sea use change; Pol - Pollution.*

A								
Component	**Dimension**	**CC**	**Exp**	**IAS**	**LSUC**	**Pol**	**Other**	**Total**
Genetic (A3)	**Genetic composition**	1.9	1.4	1.1	2.1	2.4	1.1	10
Species (A2)	**Species populations**	1.2	2.4	1.3	3.1	1.2	0.7	10
	Species traits	2.1	2.4	1.3	1.7	1.5	1.1	10

	Community composition	2.0	1.4	1.1	2.9	1.6	1.0	10
Ecosystem (A1)	**Ecosystem function**	1.9	1.7	1.3	2.4	1.6	1.1	10
	Ecosystem structure	1.5	2.1	0.8	2.1	2.3	1.1	10

B					
Component	**CC**	**Exp**	**IAS**	**LSUC**	**Pol**
Genetic (A3)	2.09	1.60	1.29	2.37	2.66
Species (A2)	1.96	2.27	1.42	2.73	1.62
Ecosystem (A1)	1.93	2.14	1.26	2.51	2.16
Overall weight	***5.98***	***6.01***	***3.96***	***7.62***	***6.43***

Table A1.3 *Weighting of Targets 1-10 in addressing Milestones A1, A2 and A3 in the global biodiversity framework. Values in the cells obtained from Table A1.2B.*

Target	**Milestone**			**Comments**
	A1	**A2**	**A3**	
T1 - spatial planning	2.5	2.7	2.4	Spatial planning focuses on ecosystems/habitats, but is relevant to species as well. Overall magnitude assumed equal to LSUC (Targets 2 & 3)
T2 - restoration	2.5	2.7	2.4	Restoration actions cross a full range across ecosystem, species and genetic actions, so equivalent to Targets 1 and 3.
T3 - protection	2.5	2.7	2.4	From IPBES 2019 direct driver quantification. Protection is equivalent to ecosystem actions and LSUC.
T4 - species recovery	1.0	4.0	1.0	Target 4 focuses on direct species actions, not attributable to direct drivers, so heaviest weight is applied to species actions, with a minor component on genetic diversity and habitat actions.
T5 - wild species use	2.1	2.3	1.6	From IPBES 2019 direct driver quantification on direct exploitation of species.
T6 - invasive alien species	1.3	1.4	1.3	From IPBES 2019 direct driver quantification on invasive alien species.
T7 - pollution	2.2	1.6	2.7	From IPBES 2019 direct driver quantification on pollution.

T8 - climate change	2.5	2.5	2.5	Increased from IPBES 2019 direct driver quantification of climate change impacts, to be equivalent to largest driver, LSUC (Targets 1, 2, 3) and equal impact across dimensions.
T9 - share benefits	2.1	2.3	1.6	Equivalent to Target 5, addresses benefit sharing from wild species use.
T10 - use/extraction	2.5	2.7	2.4	Managed ecosystems - assume equivalent to Land/Sea Use Change (Targets 1, 2, 3).

Appendix 1.2 Extended evidence base for take-home messages for individual sub-goals and milestones

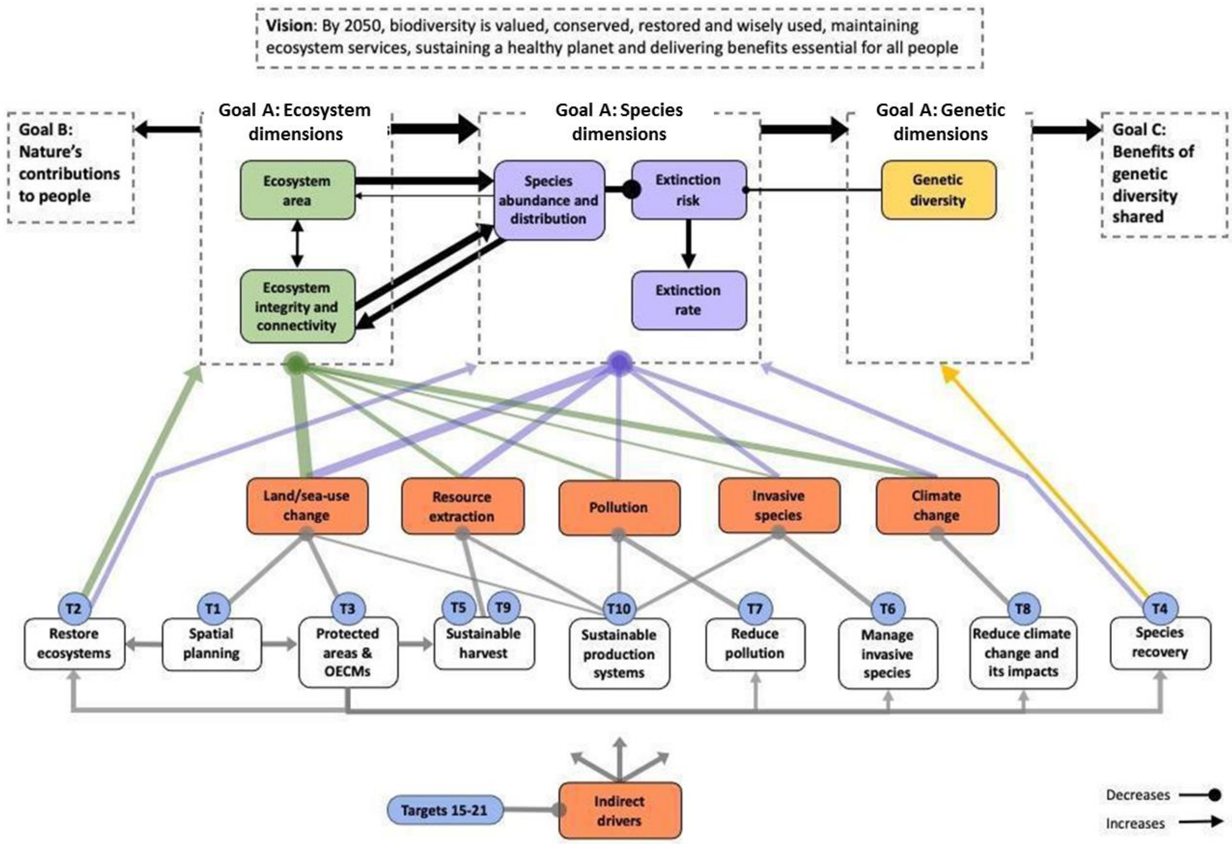


Figure A1.2 *Extended version of Figure 1.1 in section 1.3.1. This figure shows the relationship between outcomes (Goals and Goal A components, in dashed boxes), dimensions of biodiversity (A1 area, integrity and connectivity of natural ecosystems, green; A2 abundance and distribution of populations of species, species extinction rate and species extinction risk, purple; and A3 maintenance of genetic diversity, gold boxes), direct drivers (orange boxes) and targets (blue circles, where T1 is Target 1, and so forth). Relationships amongst goals and Goal A components and dimensions of biodiversity are shown by black arrows, labeled with letters*:

A. Natural ecosystems are key to sustaining species and genetic diversity: >94% of threatened species on the IUCN Red List (IUCN 2021);
B. The vast majority of genetic diversity is found *in-situ* in wild species within their native ecosystems (Nicholson *et al.* 2021), with only 3% of 7,000 useful wild plants assessed safeguarded in seedbanks, botanical gardens and other *ex-situ* stores (SCBD Biological Diversity 2020; McCouch *et al.* 2020).
C. Biodiversity in ecosystems sustain ecological functions, ecosystem services and nature's contributions for people (NCP; Díaz *et al.* 2020) in landscapes and seascapes. While single species may provide NCP (e.g., specific fisheries), they typically do so as part of the ecosystem, not alone,

and thus the main arrow to goal B comes from the ecosystem components.

D. Genetic diversity in turn supports the resources for Goal C on sharing the benefits of genetic diversity.
E. Species richness, abundance and viability increase with area of suitable habitat or ecosystems (Durrett & Levin 1996)
F. Ecosystem area is a function of the abundance and distribution of its characteristic species, especially foundation species or ecosystem engineers, as well as abiotic factors (Noss 1990; Keith *et al.* 2013).
G. The abundance and distribution of characteristic species can decline with degradation of ecosystem integrity.
H. Loss of characteristic species, and those that provide important aspects of structure and functions (such as pollinators, trophic interactions, etc.) erode ecosystem integrity (Noss 1990; Keith *et al.* 2013).
I. Depleted genetic diversity increases a species extinction risk (Mace *et al.* 2008).

Relationships between dimensions of biodiversity, direct drivers and targets are shown in coloured and grey arrows, where arrow weight is relative to impact in Figure 1.2 (as is also done in Figure 2). Some targets act directly on a given dimension of biodiversity (e.g., T4 on species recovery directly affects species abundance and distribution), while others diminish the level of a driver or its impact (e.g., T6 on invasive alien species), thus indirectly improving a dimension of biodiversity (e.g., increasing ecosystem integrity). Reducing land and sea use change has the strongest direct effects on ecosystem area and integrity, and then affecting species via habitat (A and B) and directly (e.g., when spatial planning or PA/OECM placement is designed for a species protection). Target 2, reversing impacts of land and sea use change, affects ecosystems components predominantly (and thus indirectly via habitat provision for species), although rewilding as a restoration strategy can directly affect species abundance and distribution. Although land and sea use change is the most important driver for species populations (see Figure 1.2), here the arrow is smaller because of the indirect impacts via ecosystems. While many actions interact, Target 3 (on PAs and OECMs) is likely to have direct impacts on other targets and thus drivers, through strengthened resources and incentives to manage drivers such as land and sea use change, invasive alien species management, restoration and species recovery management.

Appendix 1.3 Link between action measures and extinction risks in selected recent studies

A number of recent studies can be mobilised to illustrate the impact of action of indirect and direct drivers for land use change, as well as resulting outcomes for land use change and extinction risks for terrestrial species (excluding the effect of other threats than land use change). Some studies focus primarily on increased conservation (GBF action Targets 3 and 4, e.g., Jung *et al.* 2021) or restoration (GBF action Target 2, e.g., Strassburg *et al.* 2020) efforts but often also incorporate elements that relate to increased spatial planning efforts (GFB action Target 1) and inclusion of synergies with climate mitigation (GBF action Target 8) and other NCPs (GBF action Target 11). Other studies (Leclère *et al.* 2020; Fastré *et al.* 2021; Williams *et al.* 2021) focus on various mixes of these interventions and further actions on indirect drivers such as sustainable production and consumption (GBF Targets 10 and 16) in a context of future changes in land use, sometimes including biodiversity-friendly afforestation for climate mitigation (Kok *et al.* 2020; Soergel *et al.* 2021) and even climate change impacts on biodiversity (Kok *et al.* 2020). As illustrated in Table A1.3.1, these studies support a few key messages:

1. Impacts of drivers, different types of interventions on land use change and species extinction risks. Assuming a static land use, increasing the area effectively managed under conservation and restoration both concur to secure habitats to species that often is then translated into extinction risks reduction. Jung *et al.* (2021) estimates that while current conservation areas secure enough habitat for only 12% of species (for terrestrial vertebrates and a representative set of sample plant species) to be considered as low extinction risk (irrespective of what happens outside conservation areas), extending the area under conservation to 20-40% of land could secure a low extinction risk status for 43%-85% of species. Strassburg *et al.* (2021) estimate that restoring 4.3 million km^2 of land currently converted to cropland and pasture could reduce the number of species (for mammals, birds and amphibians) committed to extinction in the long-term from 8% in 2015 to 3%-4.6% after restoration. Taking a more dynamic view and integrating the increasing land use change pressures expected in the coming decades, Leclère *et al.* 2020 projects a further increase in habitat loss and in the proportion of species committed to extinction in the long-term in a business as usual future (due to natural land conversions to agricultural and forestry ranging in area from 2 to 10 million km^2 between 2010 and 2050), a limited reduction in such trends when considering increased conservation and

restoration efforts, but habitat gains and reducing extinction risks by 2050 (due to net change in agricultural and forestry ranging from -13.4 to 1.3 million km^2 and restoration of 4.3 to 14.6 million km^2) in a scenario combining increased conservation and restoration with sustainable production and consumption interventions (a result echoed by Kok *et al.* 2020; Soergel *et al.* 2021; Williams *et al.* 2021).

2. Importance of various aspects of ambition for restoration and conservation. When the siting of conservation and restoration areas is assumed optimal, both Jung *et al*. (2021) and Strassburg *et al.* (2020) project a fast increase in the share of species with a low extinction risk secured with the amount of land set to restoration and conservation, slowing down for larger area targets (e.g., > 40% of land). Gains of larger area targets can be in the range that corresponds to the current wording in GBF action Target 3: for example, Jung *et al.* 2021 estimates a share of species with a low extinction risk secured of 43-49% for 20% of land under effective conservation, but of 69%-85% for 40% of land under effective conservation. These studies also point to the importance of other aspects of ambition for conservation and restoration actions, such as siting of conservation and restoration areas to maximise biodiversity gains. For example, Jung *et al.* 2021 estimates of the extinction risk outcome achieved by current conservation areas (12% of species secured) contrast to that estimated when further expanding this conservation area estate to optimal locations to reach 20% of terrestrial areas (43%-49% of species secured). Similarly, the reduction of extinction debts from restoration estimated by Strassburg *et al.* 2020 is about one third lower when also imposing that the 15% target is achieved in every country.
3. Importance of an integrated view on future changes in land use, interventions and potential outcomes. Jung *et al.* (2021) and Strassburg *et al.* (2020) both illustrate the large potential benefits of taking an integrated view on restoration and conservation actions, that includes other benefits (see Target 8 and 11) such as climate mitigation (e.g., carbon stocks and removals) and other ecosystem services (e.g., water provision). When taking future land use change pressures into account, a crucial element of ambition for impacts on species extinction risks will be the consistency between conservation (T3), restoration (T2) and spatial planning (T1) action targets, net area gain goals and milestones, and implicit allowed further loss of natural areas. Future land use change pressures will be high and not all natural ecosystems will be covered by the conservation target (T3), likely leading to further loss of natural ecosystems. This is expected to increase extinction risks. Further loss of natural ecosystems should be more than compensated for by restoration (T2) to

deliver potential net gains in the natural ecosystem area. However, given the diversity of natural ecosystems and their species, and the time lags involved with recovery of ecosystems, a net gain area of natural ecosystems through large losses and restoration will likely not allow for reduction in extinction risks unless strong safeguards are in place. Spatial planning (T1) of all land and across large area, as well as active management (T4) will be key to consistently link conservation and restoration actions (as well as sustainable production and consumption actions) so that extinction risks are minimized and conflicts with alternative uses of land are limited, but additional safeguards to limit extinction risks might be needed, such explicit maximum loss thresholds for total natural ecosystem loss, zero loss targets for critical ecosystems and like for like substitutions. At last, both Williams *et al.* (2021) and Leclère *et al.* (2020) illustrate that action on sustainable consumption (T16) and production (T10) is the only way to sufficiently mitigate future land use pressure and achieve the net decrease in the area occupied by agriculture and forestry that can secure large reductions in extinction rates, consistent with Goal A. Alternative variants can exist (e.g., half-earth vs sharing-the-planet scenarios in Kok *et al.* 2020), but only strategies that combine increased conservation and restoration efforts with sustainable production and consumption efforts lead to a reversing of global terrestrial biodiversity declines from land use change. When ambitious climate change mitigation scenarios are factored in (Kok *et al.* 2020, Soergel *et al.* 2021), these need to rely on biodiversity-friendly efforts to enable a reversing of global terrestrial biodiversity declines from land use change. It is also important to note that such a transformational change strategy can mitigate trade-offs with other Sustainable Development Goals (e.g., reducing hunger) and deliver large synergies with other SDGs such as health, water or climate (see e.g., Leclère *et al.* 2020).

4. On the consistency of action targets, goals and milestones for the area of natural ecosystems in the current version of the GBF. The consistency of conservation and restoration targets with the natural ecosystem area milestones and goals is difficult to evaluate, due to lack of clarity in the definition of land categories (e.g., natural vs. managed ecosystems, degraded ecosystems). According to the IPBES Global Assessment (2019; section 2.5.2.2.1), “Estimates of the fraction of land that can still be viewed as ‘natural’ rather than anthropogenic range from under 25% [...] to over 50% [...], depending on how ‘natural’ is defined”. The current definition in GBF glossary does not clarify which definition applies, thereby making a translation in absolute area change of the relative change implied by net gain of natural ecosystems (e.g., +15% in Goal A) very uncertain. Similarly,

the degraded land mentioned in the restoration target is not easy to interpret. Cumulatively, this leaves a “missing piece” in the accounting of the area of natural ecosystems: how much area loss of natural ecosystems might be allowed so that together with the restoration it sums up to the net gain goal? Depending on how words are interpreted, it might be that either the restoration target is not sufficient to reach net area gain milestones and goals (making them infeasible, even with a zero absolute loss of natural ecosystems), or on the contrary, leaves room for further loss to natural ecosystems, with risks to other outcomes in the GBF Goals (making those infeasible). For example, in the most ambitious scenario of Leclère *et al.* 2020, 9.8 million km^2 of agriculture and forestry land (on average across models) are projected to be restored into natural ecosystems by 2050: assuming 130 million km^2 of ice-free land, this would correspond to a 30% increase in case we assume only 25% of land can currently be considered as natural (i.e., Goal A for net gain in area of natural ecosystems potentially largely attained even with further losses to natural ecosystems), but only to a 15% increase in case we assume 50% of land can currently be considered as natural (i.e., Goal A for net gain in area of natural ecosystems attained only if strictly no further loss to natural ecosystems).

Table A1.3.1 *A summary of key future land use change (absolute conversions to agriculture and forestry land area, absolute reductions in agriculture and forestry land area, net change in agriculture and forestry land area) and biodiversity (with a focus on extinction risk when available) outcomes projected for various scenarios about action on direct and indirect land use change in selected recent publications. For land use change outcomes, numbers refer to absolute area, reported in million square km (M km²) and converted to percentage of total ice-free land available (assuming 130 M km² of ice-free land). When several models are used, numbers are reported as mean value [minimum value; maximum value]. Abbreviation: ‘n.r.’ -not relevant.*

Study	Action scenario	Land use change outcome in million km² (% ice-free land area)			Biodiversity outcome (focus on species extinction risks when available)
		Conversion to ag. & forestry	Loss of ag. & forestry land	Net change	
Jung *et al*. (2021) Analysis of increased conservation efforts over terrestrial areas, in terms of spatial priorities and outcomes for	Conservation areas as of 2015 (WDPA)	n.r.	n.r.	n.r.	12% of species (terrestrial vertebrate & a representative sample of plants) with enough habitat secured by conservation area to be

extinction risks, carbon retention and water quality regulation (assuming static land use as of 2015, and efficient management of areas under conservation)					considered with low extinction risk in 2015
	-- & expansion to 20% of land area with sitting optimized for species	n.r.	n.r.	n.r.	49%
	-- & expansion to 20% of land area with sitting optimized for species, carbon and water	n.r.	n.r.	n.r.	43%
	-- & expansion to 30% of land area with sitting optimized for species	n.r.	n.r.	n.r.	72%
	-- & expansion to 30% of land area with sitting optimized for species, carbon and water	n.r.	n.r.	n.r.	58%
	-- & expansion to 40% of land area with sitting optimized for species	n.r.	n.r.	n.r.	85%
	-- & expansion to 40% of land area with sitting optimized for species, carbon and water	n.r.	n.r.	n.r.	69%
Strassburg *et al.* (2021) Analysis of increased restoration efforts over terrestrial	2015 baseline (no restoration)	n.r.	n.r.	n.r.	ca 8% of species (terrestrial mammals, amphibians and birds) committed to extinction

areas, in terms of optimal sitting and outcomes for extinction risks, carbon retention and water quality regulation (assuming static land use as of 2015, or a pessimistic future land-use change scenario)					on the long-term in 2015
	-- & restoring 15% of converted land globally with optimal sitting for extinction risks only	0	4.3 (3.3)	- 4.3 (3.3)	ca 3%
	-- & restoring 15% of converted land globally with optimal sitting for extinction risks, carbon and opportunity costs	0	4.3 (3.3)	- 4.3 (3.3)	ca 3.2%
	-- & restoring 15% of converted land per country with optimal within-country sitting for extinction risks, carbon and opportunity costs	0	4.3 (3.3)	- 4.3 (3.3)	ca 4.6%
	2050 pessimistic land use change baseline (LUH2 SSP3-RCP6.7 scenario)	11.1 (8.5) from 2015 to 2050	5.8 (4.5%) from 2015 to 2050	+ 4.1 (3.2) from 2015 to 2050	ca 10% (by 2050)
	-- & restoring 15.5% of converted land with optimal sitting for biodiversity, carbon and opportunity costs	11.1 (8.5) from 2015 to 2050	10.1 (7.8) from 2015 to 2050	+ 1 (0.8) from 2015 to 2050	ca 5% (by 2050)
Fastré *et al.* (2021) Analysis of increased	30% strategy (conservation	19.4 (14.9)	18.8 (14.5)	+ 0.6 (0.3)	20% (32%) of terrestrial bird

conservation, restoration and spatial planning efforts over terrestrial areas, in terms of optimal sitting and outcomes for extinction risks and opportunity costs (on top of a projection of land use change by 2030). Unless otherwise stated, future land-use change outcomes from 2015 to 2030.	areas expanded to 34% of land area based on various criteria and fully restored, leading to further conversions outside of conservation areas to maintain production)				(mammal) species at risk of extinction by 2030
	Optimal land use planning strategy (current conservation areas unaffected, outside current conservation areas agricultural land is redistributed to achieve food production and minimize extinction risks, with restoration and conversion)	16.3 (12.5)	14.5 (11.2)	+ 1.8 (1.4)	3% (4%)
	30% & optimal land use planning strategies	17.8 (13.7)	18 (13.8)	- 0.2 (0.1)	4% (3%)
Williams *et al.* (2021) Analysis of future land use change and biodiversity outcomes projected until 2050 for various scenarios of interventions towards ambitious goals for biodiversity. Unless otherwise stated, future land use change and biodiversity	Prolongation of historical trends (SSP2)	?	?	+ 3.35 (2.6)	5% habitat loss on average across species (terrestrial bird, mammal and amphibian species) and (6% of species with >25% habitat loss)
	-- & global land use planning (across countries)	?	?	+ 3.11 (2.4)	5% (5%)

change outcomes from 2010 to 2050.	-- & global land use planning (across countries) & food system transformation (closing yield gaps, shifting diets, reducing waste)	?	?	- 3.39 (2.6)	3% (0%)
Leclère *et al*. (2020) Analysis of future land use change and biodiversity outcomes projected until 2100 for various scenarios of interventions towards ambitious goals for biodiversity with multiple models. Unless otherwise stated, future land-use change outcomes from 2010 to 2050.	Prolongation of historical trends (SSP2)	5.3 [2.2;9.7] (4 [2;7])	1 [0.2;1.8] (1 [0;1])	+ 5.2 [2.2;9.7] (4 [2;7])	Peak 21st century loss of species committed to extinction on the long-term / 2010: 5% (range, 1–12%), trend still negative by 2050
	-- & increased conservation (ca 40% land under conservation), restoration (variable across scenarios) and spatial planning efforts	4.3 [1.9;9.3] (3 [1;7])	5 [1.8;11.2] (4 [2;8])	- 0.6 [-9.3;6.4] (0 [-7;5])	--: 2% (range, 0–3%), trend flat or slightly positive by 2050
	-- & increased conservation, restoration and spatial planning efforts & food system transformation (increase in productivity & trade, waste reduction, diet shift)	3.0 [0.6;7.6] (2 [0;6])	9.8 [4.3;14.6] (8 [3;11])	- 6.8 [-13.4;1.4] (-5 [-10;1])	--: 0% (range, 0–1%), trend positive by 2050
Kok *et al*. (2020) Analysis of future land use change, biodiversity and ecosystem services outcomes projected until 2070 for various scenarios of interventions towards ambitious goals for	Prolongation of historical trends (SSP2)	4.0 (3.1)	1.4 (1.1)	+ 2.6 (2.0)	Continued decline for extinction risks for terrestrial mammals (as measured by the Red List Index RLI indicator) and the compositional intactness of local communities over land (as measured by the

biodiversity. Unless otherwise stated, future land use change and biodiversity outcomes from 2015 to 2050. The MSA indicator also includes impacts of climate change, but the RLI doesn't.					Mean Species Abundance MSA indicator)
	-- & 'half-earth' strategy (expansion of conservation areas to 50% of land with priority for biodiversity)	4.0 (3.1)	9.8 (7.5)	- 5.8 (4.5)	RLI improved / baseline scenario and stabilized by 2050; MSA decreased / 2015 but improving trend by 2050
	-- & 'sharing-the-planet' strategy (expansion of conservation areas to 30% of land with priority for NCP supporting areas)	5.6 (4.3)	5.2 (4.0)	+ 0.4 (0.3)	RLI improved / baseline scenario but declining by 2050; MSA decreased / 2015 and declining by 2050
	-- & 'half-earth' strategy & integrated food system sustainability strategy (incl but biodiversity-friendly climate mitigation to 1.5°C)	2.8 (2.2)	11.2 (8.6)	- 8.4 (6.5)	RLI improved / baseline scenario and stabilized by 2050; MSA improved / 2015 and increasing by 2050
	-- & 'sharing-the-planet' strategy & integrated food system sustainability strategy (incl but biodiversity friendly climate mitigation to 1.5°C)	3.3 (2.5)	6.9 (5.3)	- 3.5 (2.7)	RLI improved / baseline scenario but declining by 2050; MSA improved / 2015 and stabilized by 2050
Soergel *et al.* (2021) Analysis of future energy, economy, land and climate nexus including outcomes projected until 2100 for	Prolongation of historical trends (SSP2) with current climate	?	?	+ 1.2 (0.9)	Continuous decline in the compositional intactness of local communities over land (as measured by the

various scenarios of interventions towards SDGs. Unless otherwise stated, future land use change outcomes from 2020 to 2050.	mitigation commitments				Biodiversity Intactness Index BII)
	More sustainable world (SSP1) with ambitious climate mitigation to 1.5°C (with biodiversity friendly afforestation)	?	?	- 1.8 (1.4)	Stabilization in BII by 2030 and increase after 2050
	Ambitious sustainability transformations (SDP) with ambitious climate mitigation to 1.5°C (with biodiversity friendly afforestation)	?	?	- 4.4 (3.4)	Continuous increase in BII after 2020

Appendix 1.4 Example of trawling as a driver of multiple impacts on biodiversity and the multiple benefits of halting destructive fisheries practices

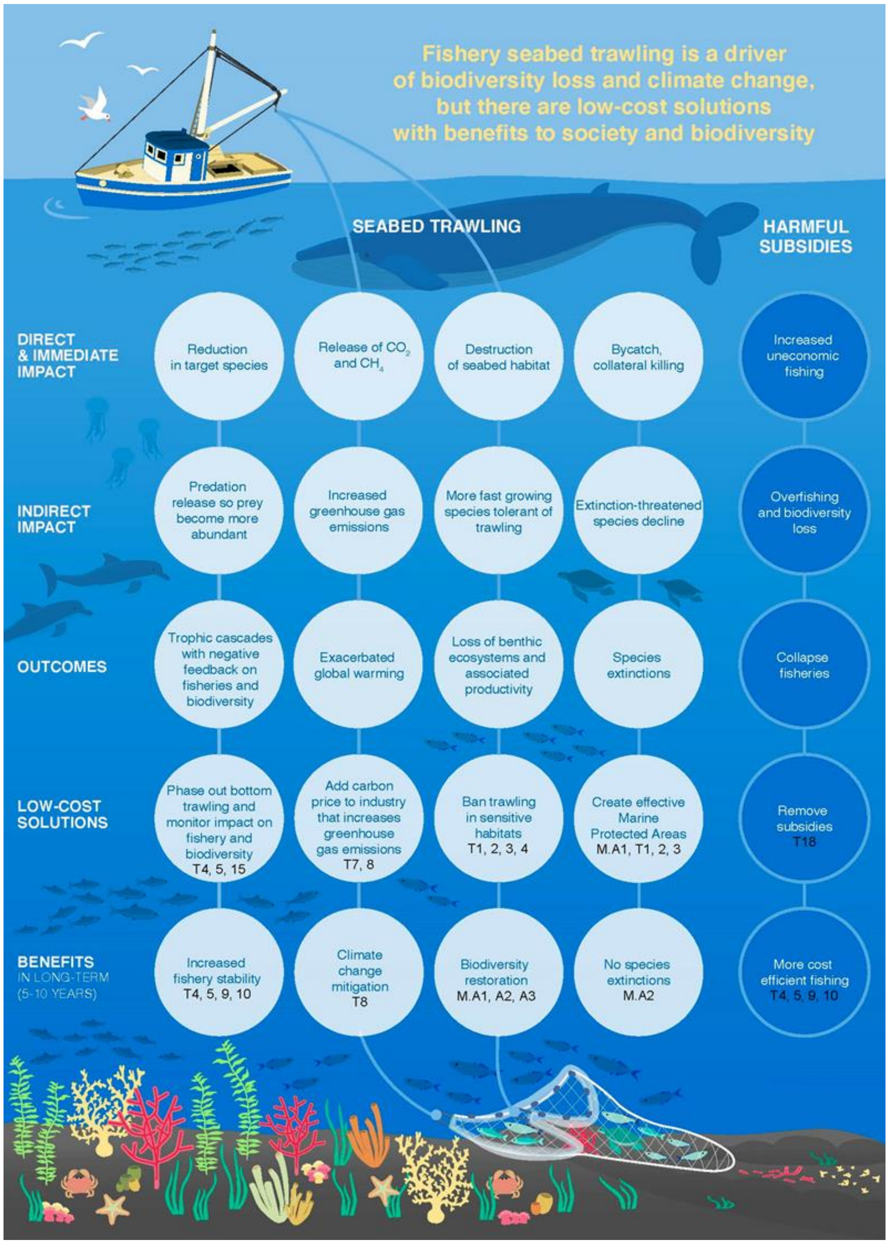


Figure A1.4 *Illustration of the multiple direct and indirect negative impacts of seabed trawling on target and extinction-endangered species, habitats and greenhouse gases emissions. The removal of harmful fisheries subsidies and low-cost management actions, including protected areas, can help restore biodiversity, benefit food and socio-economic security and mitigate against future climate change. Abbreviations M and T refer to the Milestones and Targets of the draft post-2020 global biodiversity framework.*

Appendix 1.5 Integrated sets of actions to reduce impacts of direct drivers on biodiversity

Table A1.5 *Global biodiversity framework targets and related actions to achieve ecosystem goals of increasing area, integrity and area for warm water coral reefs and Amazon tropical rainforest and their relationship to GBF targets.*

Target	Target scope	Examples of actions to achieve an ecosystem goal (from Nicholson *et al.* 2021)	Examples of actions for coral reefs (from Obura *et al.* 2021)	Examples of actions for Amazon
T1	Integrated spatial planning to retain ecosystem area and integrity	Planning, regulation and incentives to address land/sea use change	…	Terrestrial-freshwater planning for conservation (Leal *et al.* 2020)
T2	Restore ecosystem area and integrity	Restoration of abiotic environment/processes (e.g., water, fire regimes) and biotic components (e.g., direct seeding, planting, rewilding)	Coral reef active restoration	Forest restoration: post mining, natural regeneration, managed regeneration (as in indigenous land management)
T3	Expanded and effective protected areas (PAs) and other effective area-based conservation measures (OECMs)	Preventing further loss through regulation; increasing integrity and area through effective PA/OECM management and restoration action	MPAs, community management, etc.	Recognizing and strengthening Indigenous land rights (Baragwanath & Bayi 2020), designating and enforcing protected areas (Bonilla-Mejía & Higuera-Mendieta 2019; Kroner *et al*. 2019)
T4	Manage for recovery of wild species	*In-situ* management of species, including restoration action, reintroductions/rewilding and habitat management	Manage for recovery of turtles, dugong, large predatory fish	*In-situ* management of wild species, including restoration and habitat management
T5	Sustainable harvest of biota	Effective management of fisheries, bushmeat-hunting, forestry activities	Identify and develop 'climate smart' fisheries with reduced ecosystem impacts and more secure livelihood benefits	Effective management of fisheries, bushmeat-hunting, forestry activities (e.g., pirarucu fishery, tapir, Brazil nut)
T6	Manage invasive alien species	Prevent new introductions, reduce spread, eradicate or control invasive alien species to eliminate or reduce their impacts	…	

T7	Reduce pollution to levels not harmful to biodiversity and ecosystem functions	Reduce excess nutrients, biocides (pesticides etc.), and plastic waste	…	Generating alternatives to biocides and mining, monitoring impacts thereof, avoiding or capturing pollutants (e.g., artisanal gold mining challenge)
T8	Increase action on climate change to ensure resilience and minimize negative impacts on biodiversity	Nature-based solutions and ecosystem management for resilient ecosystems, disaster-risk reduction and mitigation (e.g., carbon sequestration)	Commit to strong climate change mitigation, through Paris Agreement/NDCs and national implementation of emission reductions and adaptation plans relevant to coral reefs. Establish climate adaptation plans, to for example, develop ecosystem and resource use policies anticipating potential alternative states of reefs, to maximize biodiversity and benefits after a transition.	Reducing emissions from deforestation and forest degradation, preventing and monitoring fires, post-fire management to mitigate land use change, restore forest regrowth
T9	Ensure benefits through sustainable management of wild species	Overlap with T5; management of fisheries, bushmeat-hunting, harvest	Identify and develop 'climate smart' fisheries with reduced ecosystem impacts and more secure livelihood benefits; identify alternative livelihood options and diversified income streams in coral reef landscapes	Same as T5
T11	Nature-based solutions for ecosystem services	Restore and protect ecosystems to support regulating services	Protect and restore coral reefs and associated ecosystems (e.g., mangroves) for coastal protection	Protect ecosystems and same as T2: restore degraded forests

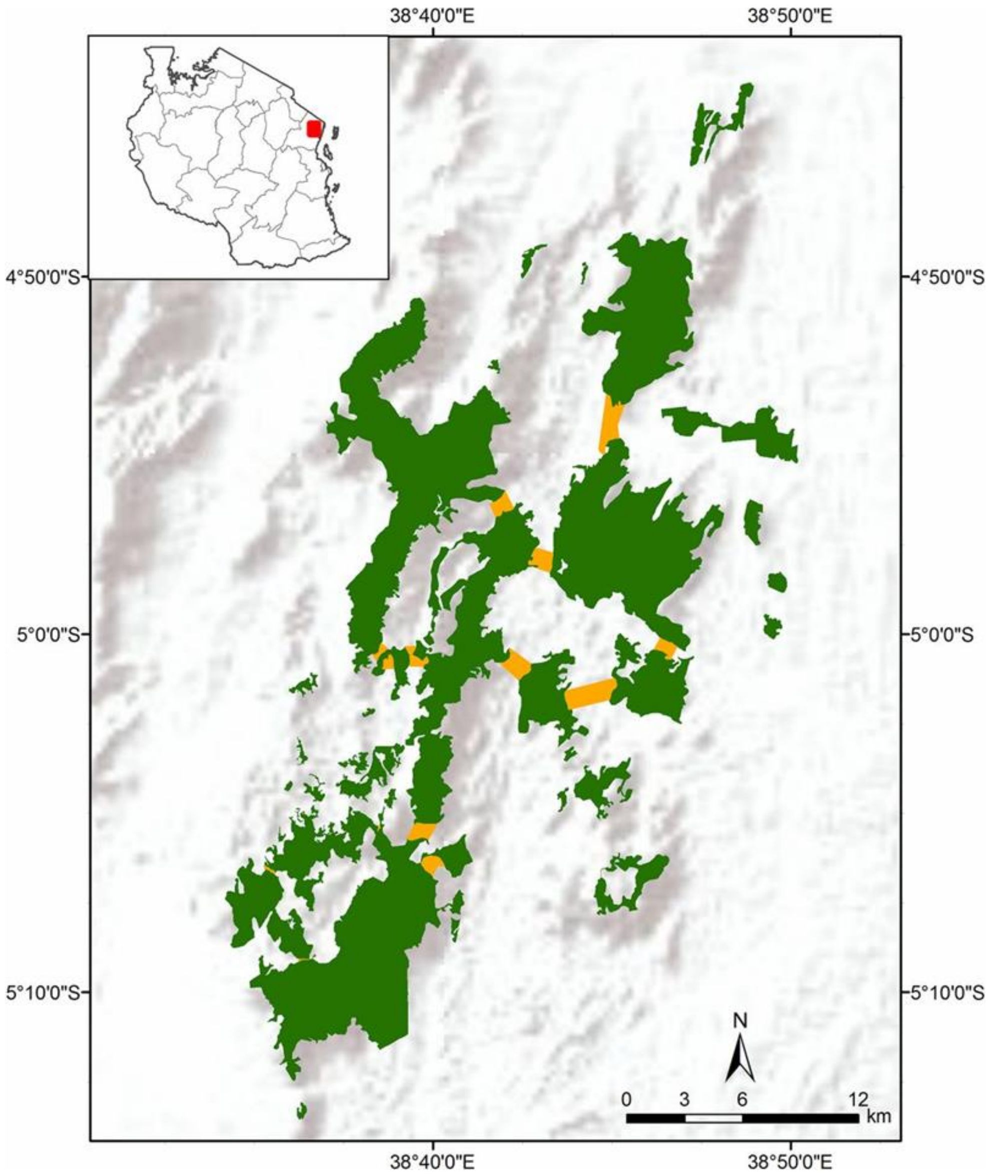
Appendix 1.6 Scenarios and models for nightscapes

The IUCN WCC 2021 calls on the Director General to assist efforts of Members and Commissions to reduce light pollution[14]. Artificial light at night is increasing in radiance and extent globally by 2-6% per year (Kyba *et al.* 2017). The brightening of the nightscapes is threatening biodiversity (Hölker *et al.* 2010) and fragmenting habitat of light sensitive species (Degen *et al.* 2016; Voigt *et al.* 2021). Artificial light at night suppresses the synthesis of the hormone melatonin, which induces circadian and seasonal rhythms (Grubisic *et al.* 2019). The suppression can reduce reproduction timing, quality and quantity on land (e.g., Robert *et al.* 2015), in the ocean (e.g., Fobert *et al.* 2019; Dybas 2020), and in freshwater systems (e.g., Brüning *et al.* 2018; Kupprat *et al.* 2021). The attraction to light sources draws species out of their ecological function and whole food webs can become distorted (e.g., Manfrin *et al.* 2017). Environmental protection laws often do not address the adverse effects of artificial light at night on biodiversity adequately. Legislative shortcomings are caused by difficulties in proving adverse effects on the population level, detecting lighting malpractice, and applying the law to situations that are in need of natural night light (Schroer *et al.* 2020). To protect biodiversity from the adverse effects of artificial light at night, strict protection of sensitive and conservation areas and important habitats for particularly vulnerable species is recommended classifying protected natural environments into different zones (Jägerbrand & Bouroussis 2021). Furthermore, standardized measurement methods and appropriate instrumentation are needed (Jechow *et al.* 2020). Connectivity for nocturnal movements and migration on land, in water and the air can be protected or restored in developing "dark infrastructure networks" likewise to green and blue corridors (Challéat *et al.* 2021). To halt the overall increase of the nightscape brightening, Falchi & Bará (2020) propose an indicator limit, distributing the emission rate among affected communities, and planning with a long-term perspective policy. The United Nations Office for Outer Space Affairs (UNOOSA) filed a report on the effects of artificial light at night and compiled 13 recommendations to mitigate the impacts of artificial light on humans, flora, and fauna[15].

[14] https://www.iucncongress2020.org/motion/084
[15] https://www.iau.org/static/publications/dqskies-book-29-12-20.pdf

Appendix 2.1 Examples of action and estimated recovery

BOX 2.1 Restoring forest connectivity increases effective area and can reduce the size of an extinction debt thereby contributing to Milestones A.1 and A.2. Newmark *et al.* (2017) found that regenerating 8,134 ha of forest connections 1 km in width among the largest and closest fragments at 11 locations in the Eastern Arc Mountains of Tanzania would create >316,000 ha in total of restored contiguous forest. This conservation action is expected to increase the persistence time for species by a factor of 6.8 per location or ~2,272 years, on average, relative to individual fragments (*Source*: Newmark *et al.* 2017).



BOX 2.2 Re-building marine life (*Source*: Duarte *et al.* 2020).

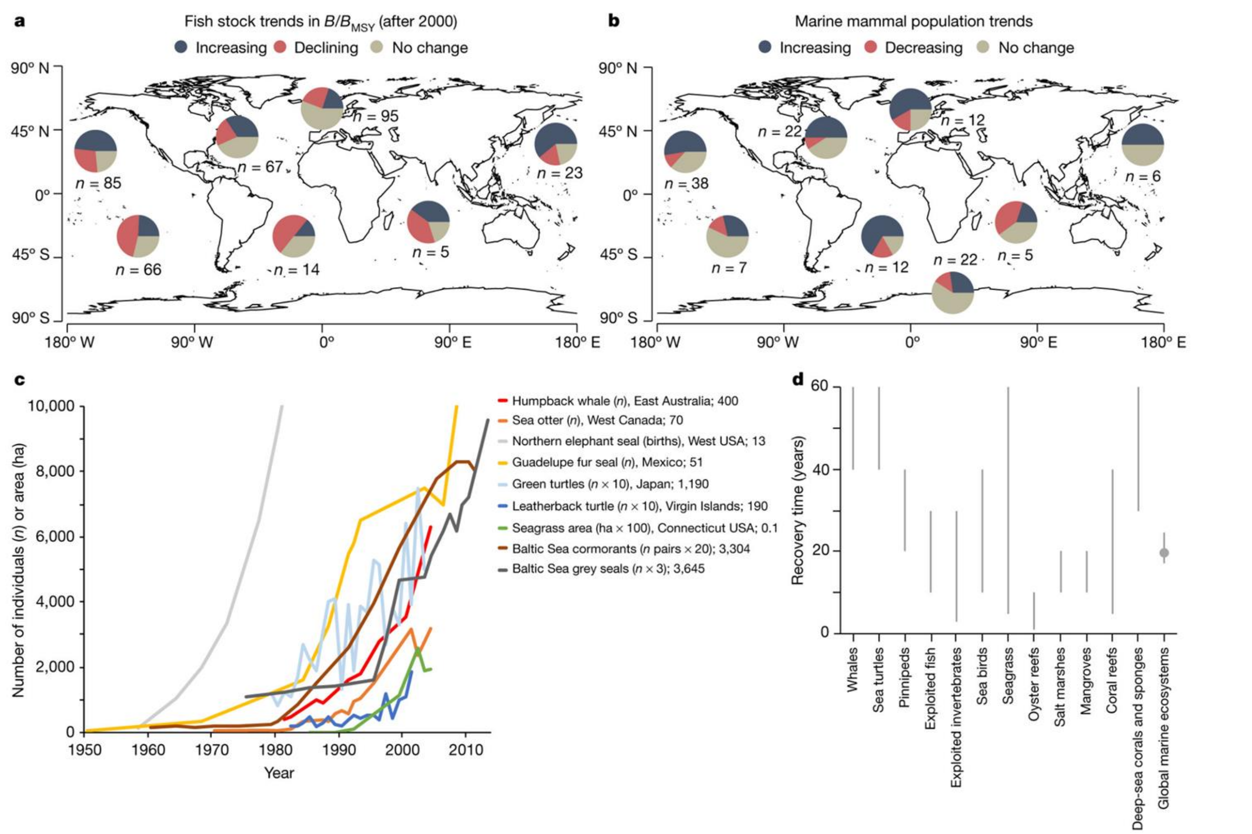
Achieving Goal A and Goal B will require rebuilding the marine life-support systems that deliver the many benefits that society receives from a healthy ocean. The figure below shows the recovery of marine populations, habitats and ecosystems following past conservation interventions. Recovery rates across studies suggest that substantial recovery of the abundance, structure and function of marine life could be achieved by 2050, if major pressures—including climate change—are mitigated.

Panel a) Current population trends in scientifically assessed fish stocks based on the ratio of the annual biomass (B) relative to the biomass that produces the maximum sustainable yield (BMSY).

Panel b) Percentage of assessed marine mammal populations that showed increasing or decreasing population trends or showed no change.

Panel c) Sample trajectories of recovering species and habitats from different parts of the world. Units were adjusted to a common scale by multiplying or dividing as indicated in the legend (n×); numbers at the end of the legends indicate the initial count at the beginning of the time series.

Panel d) Range of recovery times for marine populations and habitats and mean ± 95% confidence limits recovery times for marine ecosystems. Lines indicate the reported range; where extending to 60 years, the maximum recovery time is 60 years or longer.



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