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Ecological Solutions and Evidence

PERSPECTIVE

Operational perspectives for biodiversity indicators

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Abstract

1. Smart biodiversity indicators are needed not only for assessing and managing biodiversity (change) but also for informing target setting for environmental policies. This need has created a plethora of indicator frameworks, which are widely debated in terms of their design and usefulness. We propose that these discussions would benefit from more clearly separating different types of indicators and more operationally linking them to management targets and biodiversity goals.
2. Decision makers often consider the multitude of biodiversity indicators as being *complicated*, whereas scientists emphasize that they barely reflect how *complex* biodiversity is. It is therefore important to differentiate clearly between indicators for *diagnosing* (the drivers of) biodiversity change and indicators for *steering* policies. While the former must be scalable in time and space and reflect the full complexity of biodiversity, the latter need long-term visions and simplicity.
3. *Management targets* such as proportions of protected areas or mitigation of biodiversity drivers have the advantage of being operation-oriented, well quantifiable and immediately responsive to change. Achieving a management target, however, does not necessarily equal achieving a biodiversity goal. Likewise, *management indicators* that track how well management targets are achieved cannot replace diagnostic or steering indicators.
4. Solution: *Biodiversity goals* such as 'bending the curve' can only be achieved by closely linking diagnosis, steering and management, while accepting that their distinct design principles need to be addressed. Being aware and accepting such tailored types of different indicators and management targets could strongly improve the interplay between science and policy to reverse negative biodiversity trends in the future.

KEYWORDS
assessment, biodiversity indicators, biodiversity strategy and actions plans (NBSAP), complexity, cross-realm, Kunming-Montreal global biodiversity framework (KM-GBF), management target, operational, steering

1 | INTRODUCTION

Biodiversity change is a global political concern as Earth's habitability for humans ultimately depends on biological processes, which in turn depend on the identity and variation of marine, freshwater and terrestrial life. In the past decades, many political instruments have been developed to address this concern ranging from the Kunming-Montreal Global Biodiversity Framework (KM-GBF; CBD, 2022b) over supranational regulations such as the European Union' Biodiversity Strategy (EU, 2021) and Framework Directives (EU, 2000, 2010, 2017) to national biodiversity strategies and action plans (NBSAPs). By mid-August 2025, 55 parties of the Convention on Biological Diversity (CBD) had submitted the requested NBSAP within the KM-GBF framework (Affinito et al., 2024; CBD, 2022a). In addition, also the private sector (economic and financial companies) starteds disclosing how they integrate biodiversity into their decision-making and risk management (TNFD, 2023).

All these efforts share a similar narrative of 'bending the curve': we need to invest in conservation to halt the current biodiversity loss and additionally in transformation to invert the negative trend into a biodiversity positive future, for example, through restoration (Leadley et al., 2022; Leclère et al., 2020). This narrative requires diagnosing 'underlying causes of biodiversity loss', managing 'determinants of transformative change' and steering 'options for achieving the 2050 Vision for Biodiversity' (IPBES, 2024).

Bending the curve requires smart and meaningful indicators that depict the status and trend of biodiversity as well as measure the progress made towards formulated biodiversity goals. As a consequence, a wide array of indicator frameworks exists (Feld et al., 2009; Pereira et al., 2013; Teixeira et al., 2016; Affinito et al., 2025; BDM (Coordination Office), 2014), where each framework consists of multiple indicators (which themselves may have multiple individual metrics) that capture different aspects of biodiversity and its change. These provide us with a plethora of information, which can cause confusion or be perceived as too complex, especially as different indicators can yield vastly different results despite the same underlying biodiversity change (Hill et al., 2016).

The KM-GBF's vision for 2050 formulates a joint goal for biodiversity, which is shared among scientists, practitioners and biodiversity-aware decision makers. However, scientists are expected to understand how and why biodiversity is changing, decision makers are expected to set realistic and useful goals and practitioners are expected to understand which management actions allow bending the curve. We base our perspective on the notion that each of these demands needs operational indicators, but these needs are so divergent that no single indicator (not even an indicator framework) can serve all at once. At the same time, it is impossible to cover the entire information, as the Taskforce on Nature-related Financial Disclosures (TNFD, 2023) alone reported over 3000 unique biodiversity-related metrics.

In this perspective, we address this dilemma by first addressing the common notion that diagnosing biodiversity is (too) *complex* (Section 2). We then argue that explicitly acknowledging essential functional differences between diagnostic and steering indicators helps design assessments and strategy development (Section 3). Furthermore, we argue that management targets are derived from diagnosis and steering, but they require different indicators (management indicators), which cannot replace either diagnosis or steering indicators (Section 4). Finally, we discuss why the development of indicator frameworks for all three purposes needs to happen in an integrated manner across disciplines, user groups as well as realms (Section 5).

2 | COMPLEX, BUT NOT COMPLICATED

Biodiversity has many facets encompassing, for example, taxonomic, evolutionary and functional differences, biotic interactions, the abundance in populations and the intraspecific variability between individuals within populations, the species composition of communities and the size as well as functioning of ecosystems (Antonelli, 2022; Pereira et al., 2013). Each of these facets requires different ways of measuring their status and trends, but at the same time, each metric has its own biases and limits, both statistically and biologically (discussed elsewhere, e.g. Magurran & McGill, 2011; Chao et al., 2014). Moreover, even for a single driver (e.g. warming) in a single ecosystem type (e.g. lake), each of these facets can change independently or in concert. Higher temperatures can reduce the size of individual organisms within populations (Albini et al., 2025), alter the size and intraspecific composition of populations (van Dorst et al., 2019), lead to a temporal mismatch between interacting species (Kharouba et al., 2018), change species and trait composition by colonizations, extirpations and shifts in relative abundance (Hillebrand et al., 2018; Khaliq et al., 2024), shift the entire functioning of the system (Yvon-Durocher et al., 2010) and even alter the size of the ecosystem itself (Woolway et al., 2022). This long list is still non-exhaustive as it ignores links between ecosystems (lake-catchment) and the interaction of warming with other anthropogenic drivers (nutrients, pollution, land use).

Thus, the numerous ways in which biodiversity can change amount to a seemingly overwhelming complexity, which is often seen as an impediment to verify and report on biodiversity change in a way that mandates political action (Ekardt et al., 2023). While the science–policy interface on climate change relies on temperature as an easily communicated, physically well-defined indicator, even the most consistent biodiversity indicator frameworks such as the essential biodiversity variables (Pereira et al., 2013) deal with multiple, in part abstract metrics.

Before we deal with the need to capture this complexity for diagnosis, but to simplify it for steering (Section 3), we would like to emphasize that the complex nature of biodiversity is not a nuisance, but rather its main asset. This complexity ensures the functioning of the biosphere and thus the provisioning of services forming the basis for human life on Earth (e.g. climate, food, oxygen, raw materials). Life on Earth has evolved into an incredible and fascinating array of solutions for the main necessities to obtain matter and energy, grow, reproduce and disperse. All of these facets are part of a 'tangled bank' (Darwin, 1859) that allows ecosystems to function and more diverse ecosystems to be more resilient (Levin, 1998). It is this complexity that ultimately provides the conditions for humans to live on Earth, and it will likely be humanity's greatest ally in a rapidly changing climate, as it enables ecosystem resilience through the unprecedented rate of reorganization and adaptation required from species and ecological communities (Pörtner et al., 2021).

Any attempt to report biodiversity change in a single framework (or worse, a single number) must, therefore, fail as it ignores the multifaceted nature of biodiversity (spatial, temporal, community, species, functional, genetic). At the same time, reporting on several independent biodiversity facets often generates an 'incoherent' impression of biodiversity change, which has given biodiversity indicators the reputation of being too 'complicated' for decision-making and management (Sobkowiak, 2023). We argue that these different needs mandate two different indicator frameworks, one for diagnosing biodiversity change, which needs to encompass all complexity, and one for application in political steering and science communication, which requires a reduction of the complexity.

3 | DIAGNOSTIC AND STEERING INDICATORS

Diagnosis and steering have different aims, different audiences and therefore fundamentally different design principles (Figure 1). Diagnosis aims at system understanding. Therefore, diagnostic indicator frameworks need to detect the full dimensionality of biodiversity change, which requires measuring the ecological status and trends of multiple biodiversity facets and combining these with causal inference and attribution to drivers (Gonzalez, Chase, & O'Connor, 2023). To do so, the diagnosis of status and trends requires multidimensional indicator frameworks that reflect the multiple facets of biodiversity (Pereira et al., 2013).

Diagnostic indicators address mainly an audience conducting assessments, while steering indicators need to be communicable beyond those groups as they are defined in socio-political contexts and reflect a 'policy-relevant phenomenon used to set environmental goals and evaluate their fulfilment' as their indicandum (Silva del Pozo et al., 2023). 'Bending the curve', for instance, is such a goal formulation, and the KM-GBF headline indicators give numerous examples of steering indicators for achieving biodiversity goals (https://www.gbf-indicators.org/). The first listed indicator 'Red List of Ecosystems' is a great example as an increase in the number of red-listed ecosystems helps to realize that our policies steer away from the accepted goal, but it does not help in diagnosing the causes. In fact, most headline indicators in the KM-GBF such as red lists of species or ecosystems, the extent of natural ecosystems or the proportion of small populations ($N < 500$) are steering indicators (Hébert et al., 2025). Some indicators try to aggregate steering and diagnostic aspects, such as the Living Planet Index, which however is heavily debated (Almond et al., 2020; Hébert & Gravel, 2023; Leung et al., 2020; Toszogyova et al., 2024).

Since steering indicators by definition have a normative component, they need to be relevant over longer time-scales and reflect the spatial scale of the goals, which tend to be regional (i.e. often bound to political borders such as nations or federal states) or global (KM-GBF). By contrast, diagnostic indicators mainly need short-term sensitivity and responsiveness to drivers and mainly operate at the local to regional scales of monitoring. In terms of responsiveness, indicators can be differentiated as leading, coincident and lagging (Stevenson et al., 2021). In this context, leading indicators respond before biodiversity change manifests (early warning), while coincident and lagging indicators react during or after changes in biodiversity, respectively.

Steering indicators should react at least simultaneously with the change of the variable of interest, but preferably they allow preventive adjustment of the steering, that is, be leading indicators in order to prevent certain developments (Figure 1). In this respect, many headline indicators fail as they show very slow responses to change. It takes years to decades to detect a deterioration of red list status for mammal and bird species (Piipponen-Doyle et al., 2021) or to monitor and report changing numbers of newly established introduced species (McGeoch et al., 2023). In the opposite direction, these indicators will also lag behind conservation success (Watts et al., 2020) and thus may trigger the counterfactual conclusion that conservation or restoration efforts are not working.

The same is true for diagnostic indicators that often de facto lag behind the changes they describe because biodiversity does not immediately respond to changes in environmental conditions. For example, extinction debt delays the local loss of a species as long as individuals persist despite declining abundances, while immigration credit delays the local gain of a species, for example, due to dispersal limitation, and both affect the number of species monitored over time (Jackson & Sax, 2010; Kuczynski et al., 2023).

As a result, while leading or coincident indicators would be preferable, many changes in biodiversity we measure today reflect past environmental or anthropogenically triggered shifts. This inertia does not only inhibit understanding biodiversity change and its attribution to drivers but also fails to deliver the

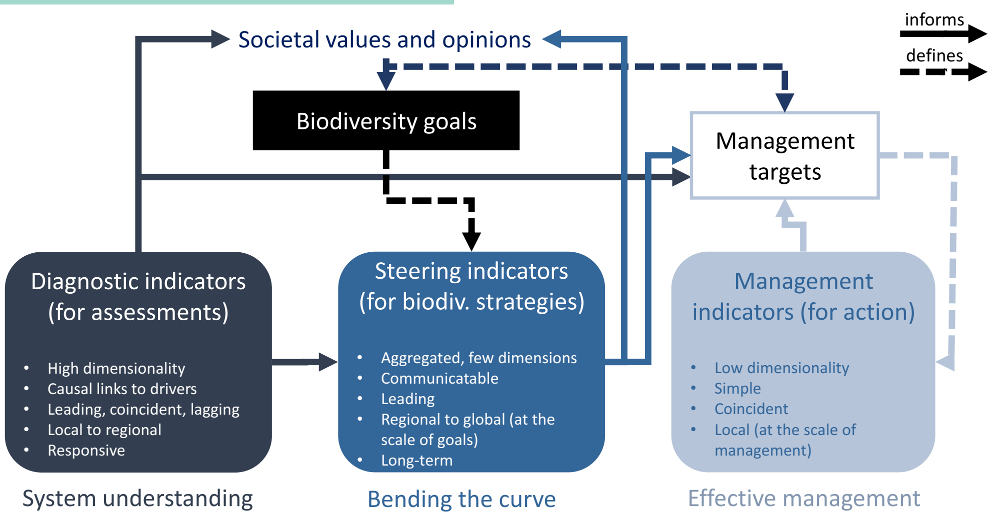

FIGURE 1 Different types of indicators for biodiversity status and trends, goals and management and their logical connections. Diagnostic indicators serve to assess biodiversity and understand its change. They deliver information to the societal and political discussion of biodiversity goals. Goals cannot be monitored by understanding, but need steering indicators, which also need feedback in the decision-making process. The steering decisions lead to management targets; the efficiency of this management needs its own indicators leading to, for example, conservation and restoration actions.

urgency needed regarding biodiversity action. The KM-GBF is a unique—and perhaps the only—opportunity to establish a global biodiversity observation system that can be designed to fulfil both diagnosis and steering needs (Affinito et al., 2025; Gonzalez, Vihervaara, et al., 2023). Affinito et al. (2025) concluded that the success of the KM-GBF will depend on the ambition of the parties to cover more than the so-called headline indicators and to embark on a joint and global learning exercise as 12% of the KM-GBF elements are still lacking indicators. For example, Target 10 ('Enhance Biodiversity and Sustainability in Agriculture, Aquaculture, Fisheries, and Forestry') so far has no fisheries or aquaculture headline indicator.

Despite the different audiences and design principles, it will be crucial that assessment experts, political and societal actors co-design biodiversity goals together to ensure that steering indicators lead to the same conclusions as the higher resolved diagnostic indicators, which they should be based on (Figure 1). The good news is that science is well prepared to take on this task. In a recent systematic review of the marine literature, Dajka et al. (2025) found that the indicators discussed in the KM-GBF context not only surprisingly well cover all major categories of essential biodiversity variables but they also align with the foci of the last decade of marine biodiversity research. Based on >250 scientific papers and 29 biodiversity indicators, species populations, community composition, ecosystem structure and ecosystem functioning received similar attention in science and policy; only genetic and trait-based biodiversity was underrepresented in the indicators. Hence, enough evidence exists in order to align diagnostics and steering.

The bad news is that monitoring for diagnosis requires significant additional efforts and money. As a result, management targets are often formulated and evaluated by their own management indicators. However, these often start their own trajectories independently of the actual biodiversity trends.

4 | MANAGEMENT INDICATORS ARE NOT BIODIVERSITY INDICATORS

In the context of this article, we use the term management in a broad sense to comprise any human measure that is intended to bring the status of biodiversity closer to a predefined goal (Figure 1). Management is often guided by its own explicit targets ('30% area protected by 2030'), which define steps towards achieving the long-term overall goals. Management targets then themselves are tracked by indicators, for example, by recording the progress towards these targets quantitatively (km^2 or % area protected). Such management indicators are highly attractive because they are well-defined, often quantitative, easy to understand and their trajectories can be tracked comparably fast (Figure 1). For example, every newly established protected area brings the indicator '% area protected' closer to the predefined management target.

Management indicators are also needed for biodiversity credits, which have recently been proposed as means to fund conservation and restoration measures (Antonelli et al., 2024). This proposal has quickly led to the identification of a range of problems, one of which is the need to measure the impact of these credits on management goals and biodiversity status (Law, 2025; Wauchope et al., 2024).

It is important to acknowledge, though, that despite the 'ease' of tracking management targets, they cannot replace steering or diagnostic indicators. In fact, over-reliance on management targets can obscure the real drivers of biodiversity loss and jeopardize conservation efforts (Lemieux et al., 2019). To reduce climate change impacts on targets, the EU has set explicit targets for the proportion of biofuel in energy consumption (EU, 2018), but given the potential negative impact of biofuel production on biodiversity (Tudge et al., 2021), focusing only on this target without diagnostic indicators of biodiversity change will have negative consequences for biodiversity. Generally, if decision makers focus solely on meeting numerical targets (e.g. increasing protected area coverage), they risk neglecting critical factors like habitat quality, ecosystem connectivity or species interactions in creating actions. A protected area, for instance, does not automatically lead to species recovery if it lacks effective management. Similarly, an increase in forest cover does not always equate to higher biodiversity if the new forests are monocultures or degraded habitats. Biodiversity goals should be formulated in outcome space (e.g. tropical coral reefs shall persist), not as a management target (x % of coral reefs protected). Mixing these two concepts may have highly negative consequences (see Fisher et al., 2024 for a more in-depth discussion).

Thus, management targets and their indicators are essential tools for conservation, but they cannot substitute diagnostic and steering biodiversity indicators. To genuinely address biodiversity loss, management actions must be closely linked to indicators that capture the complexity of ecosystems and long-term trends. A well-integrated approach that combines concrete conservation measures with robust biodiversity assessments is necessary to ensure lasting and effective progress.

5 | BENDING THE CURVES TOGETHER

We wrote this perspective based on a notion of opportunity and urgency. The KM-GBF and the coincident agreement on Biodiversity Beyond National Jurisdiction (https://www.un.org/bbnjagreement/en) are the most ambitious multilateral agreements to safeguard the biological basis of the Earth system. At the same time, the rate of nature destruction, climate change and biodiversity loss—in concert with the knowledge of how time-lagged biodiversity responds to these changes—creates a feeling of immediacy that stands in stark contrast to how slowly humanity is making progress towards biodiversity protection and restoration. While the complexity of biodiversity is often mentioned as an impediment to faster action, the implementation of measures is often impeded by the complexity of governance structures organizing the interactions of actors and regulations across levels and sectors (Paavola et al., 2009). Developing indicator frameworks should be a coordinated, joined and concerted effort across disciplines, realms (terrestrial, freshwater, marine) and spatial units (countries). In fact, however, we see multiple independent developments and little prospect for change once a framework has been adopted.

We argue here that biodiversity goals such as 'bending the curve' can only be achieved by closely linking diagnosis, steering and management. Scientists, decision makers and managers face the challenge that this interlinkage needs to happen *simultaneously* to the development of assessments, strategies and actions. The development of indicator frameworks addressing diagnosis, steering and management needs to reflect the clear logical dependencies between them, but at the same time account for the differing functionalities and design principles of the different indicator types. Steering indicators do not enable diagnosis and attribution, just as management indicators cannot replace steering. Outcome goals ultimately require both valid steering indicators and an in-depth diagnosis to securely identify and adequately address root causes for biodiversity change (e.g. warming, acidification, eutrophication).

We agree with Affinito et al. (2025) that scientists, governments and societies embark on an unprecedented learning exercise to cope with the challenge of bending the curve. Conceptualizing the entire bandwidth from system understanding to effective management more clearly will improve the observation and monitoring we need to achieve our biodiversity goals and the indicator framework derived from these observations. Furthermore, if scientists, practitioners and decision makers can agree that all indicators are (and will remain) imperfect, we can stop binding resources in the search for a perfect solution. This 'holy grail' of biodiversity indications does not exist, and we need to move from more research on indicators to more attribution, steering and action. Otherwise, biodiversity research and decision-making will end up in a 'trap' comparable to that of climate change research. There, science continues to pile up evidence on man-made climate change, while enough evidence on causes and needed actions was established long ago, even with stakeholders that had contrary agendas (Supran et al., 2023). We consider emphasizing uncertainty, complexity and knowledge gaps as important scientific contribution, but this must not delay actions towards sustaining our biosphere.

As this biosphere is highly interconnected between terrestrial, marine or freshwater, we are negatively surprised by how often scientific and policy discussions around biodiversity still happen within single realms. This is inadequate from diagnosis, steering and management perspectives, as most changes in biodiversity and ecosystems are driven by processes across multiple realms. Neither climate change nor altered biogeochemical cycles stop at ecosystem boundaries, which are additionally linked through organisms' life cycles and reciprocal subsidies (Hermoso et al., 2021; Scherer-Lorenzen et al., 2022). Last but not least, humans telecouple realms and regions of consuming and producing countries, leading to a shared responsibility of biodiversity outcomes (Zinngrebe et al., 2024). Societal transformation is only possible on land, where humans live, but must target sustainability together across realms.

6 | SUMMARY

We argue that the discussion on biodiversity indicators would profit from (i) allowing diagnostic indicators to capture as many different biodiversity facets as needed, (ii) formulating outcome-oriented steering indicators to guide public discussion and policy making and (iii) avoiding the tracking of management targets as a replacement for biodiversity assessments. It would improve communication about biodiversity change if different indicators were mapped along their different purposes, and it would improve biodiversity research and management if the interrelationships between these indicator types were well understood. Any reporting of data leading to indicators across spatial scales, realms and taxa needs interoperable machinery to allow the leading or at least 'real time' diagnostics. A major but highly needed task across all countries, given recent developments of rebuilding national barriers, increasing federalism and reduced funding in global biodiversity conservation actions.

AUTHOR CONTRIBUTIONS

Dorothee Hodapp and Helmut Hillebrand planned the activity. Marten Winter, Anika Happe, Markus Weitere and Helmut Hillebrand outlined the manuscript; all authors wrote the first draft together and contributed to the editing of the manuscript.

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