Global targets that reveal the social-ecological interdependencies of sustainable development

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Abstract

We are approaching a reckoning point in 2020 for global targets that better articulate the interconnections between biodiversity, ecosystem services and sustainable development. The Convention on Biological Diversity's (CBD) post-2020 global biodiversity framework and targets will be decided as we enter the last decade to meet the Sustainable Development Goals (SDGs) and targets. Despite recent findings of unprecedented declines in biodiversity and ecosystem services and their negative impacts on SDGs, these declines remain largely unaccounted for in the SDG's upcoming "decade of action". We use a Social-Ecological Systems (SES) framework to develop four recommendations for targets that capture the interdependencies between biodiversity, ecosystem service and sustainable development. These recommendations, which are primarily aimed at the CBD post-2020 process, include moving from separate social and ecological targets to social-ecological targets that: account for (1) the support system role of biodiversity and (2) ecosystem services in sustainable development. We further propose target advances that (3) capture social-ecological feedbacks reinforcing unsustainable outcomes, and (4) reveal indirect feedbacks hidden by current target systems. By making these social-ecological interdependencies explicit, it is possible to create coherent systems of global targets that account for the complex role of biodiversity and ecosystem services in sustainable development.

Introduction

We are currently experiencing biodiversity loss at unprecedented rates, with virtually all indicators of the global state of biodiversity declining as a result of human activities affecting large tracts of land (75%), wetlands (85%) and oceans (66%)[1]. These findings are deeply troubling from a conservation perspective, but also herald substantial consequences for ecosystem services, human wellbeing and the achievement of the United Nations' Agenda 2030 and the Sustainable Development Goals (SDGs; Table 1)[2,3]. The world is now at an inflection point for achieving the SDGs, with only a decade to make progress on the 2030 targets and a clear need to accelerate action on the heels of the first United Nations Summit on the SDGs, held recently in late-2019. There is accruing evidence linking biodiversity to the SDGs, both as a goal in and of itself, as well as through its multiple material and intangible benefits, contributions and values for sustainable development (which we hereafter refer to as ecosystem services)[1]. However, both biodiversity and ecosystem services remain chronically undervalued and largely missing in high-level discussions around the SDGs. In fact, in the Secretary General's report on the Progress toward the SDGs, there is only one mention each of biodiversity, ecosystems and environment in the eight systemic and cross-cutting focus areas identified to accelerate implementation for the coming decade, none of which focus on or include biodiversity and ecosystem services[4].

Part of this underrepresentation is linked to the challenge of quantifying the impact of biodiversity and ecosystem services on SDG achievement, which is hindered at several levels, from the articulation of the 17 SDGs themselves to the targets that set the level of ambition for those goals and the indicators used to measure progress. In the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) Global Assessment (Table 1), this proved a major impediment to a comprehensive review of the scientific evidence linking trends in biodiversity and ecosystem services to the SDGs (Figure 2). A failure to make these connections is problematic across many fronts and requires urgent attention that can inform not only the SDG processes, but also, importantly, the Convention on Biological Diversity's (CBD) post-2020 global biodiversity framework (Table 1) currently in development. To fill this gap, we use a Social-Ecological Systems (SES) analytical framework to highlight interdependencies between biodiversity, ecosystem services and sustainable development in order to inform these ongoing and future processes.

Social-ecological feedbacks and the SDGs

The SDGs evolved from the Millennium Development Goals and were envisioned to more comprehensively consider the role of biodiversity and ecosystem services in development[5]. In fact, the SDGs were envisaged as a means to integrate all three dimensions of sustainable development: social, economic and environmental into a unified 'plan of action for people, planet, and prosperity'[6]. This

unified plan makes clear that indivisibility and interconnectedness lie at the heart of the United Nation's Agenda 2030, requiring consideration of all SDGs as an integrated whole[7]. However, the current articulation of these 17 SDGs has resulted in a fragmented set of sector-specific goals, largely relegating biodiversity to a single goal (SDG 15). This fragmentation obscures biodiversity's relevance across all goals, including through its role in providing ecosystem services, potentially reinforcing its undervalued nature across the SDGs. Several scholars have suggested the adoption of a systems approach, which treats the separate SDGs as interlinked and focuses on mapping the co-benefits (synergies) and trade-offs between goals[5,8,9]. These system approaches have been applied to all SDGs[10], as well as for specific sectors e.g. energy[11] and have helped to highlight goals with many positive synergies and those where trade-offs are a concern. However, the approaches still tend to treat SDGs as a complicated system reducible into separable parts with one-way interactions. Although analytically appealing, such systems approaches tends to be at odds with the notion of an "indivisible whole" being more than the sum of its (sectoral) parts.

On the other hand, SES approaches recognise that (1) social systems (including economic systems) and ecosystems are inextricably linked by interactions and interdependencies of social and ecological processes; and (2) that these interactions produce "emergent" system-level outcomes and properties (e.g. resilience) with effects different from those of the individual parts (Figure 1)[12,13]. An SES approach challenges the assumption that one can study the separate social, ecological and economic systems of sustainable development to understand their properties and trends, and from this to reconstruct a holistic picture of sustainable development outcomes. Instead, SES research offers an integrated perspective of humans in nature and has been demonstrated to offer avenues, new methods and data from which to engage with the SDGs in a more "whole-system aware" manner[14-21].

A key contribution of the SES approach is a focus on feedbacks (Figure 1). Feedbacks occur where an initial interaction between two or more elements feeds back to the initiating element or process with positive i.e. reinforcing or negative i.e. dampening outcomes. Feedbacks provide an entry point to adopt a complex SES approach to understand and analyse SDG interdependencies with biodiversity and ecosystem services[22]. When direct, these feedbacks are relatively straightforward to account for, but they can also be indirect and disconnected over space and/or time and therefore not directly affecting the original source of the change, e.g. the resource user[23]. Biodiversity and ecosystem service declines are often at the heart of such feedback effects as both the result of indirect feedbacks, as well as the trigger for new indirect feedbacks important for human wellbeing in the future[24], for specific groups of people[25] and in other geographies[26]. These cascading social-ecological feedback effects are increasingly important to capture as societies urbanise and "decouple" from local ecosystems and their feedback effects[23].

Furthermore, social-ecological feedbacks are often behind lock-ins or traps that underlie some of the challenges the SDGs aim to address[27] such as marginalisation, extreme poverty, or vulnerability[28]. Biodiversity and ecosystem service loss is increasingly recognised as important in many of the feedbacks behind these traps, but is still largely absent from the interventions implemented[29]. Therefore, new approaches for studying emergent phenomena such as these non-linear dynamics and the feedback processes that give rise to them are key[12,30,31].

Biodiversity and ecosystem services in development

The global IPBES assessment found that biodiversity and ecosystem services are important for all 16 SDGs (SDG 17 was not assessed)[1]. However, the assessment could only assess the consequences of trends in biodiversity and ecosystem services for 35 of the 150 SDG targets examined, highlighting negative or insufficient progress in all 35 (Figure 2). While data and knowledge gaps proved a limiting factor, of particular relevance was the finding that current target articulation obscures or omits the relationship with biodiversity and ecosystem services for the vast majority of targets (Figure 2).

These findings echo calls like those made by Mace et al.[32] to set more ambitious goals and targets for the conservation and restoration of biodiversity. They further make evident that the current formulation of the global goals, targets and indicators being used to track progress to the SDGs, severely limits our ability to accurately determine how biodiversity and ecosystem services are affecting the SDGs and sustainable development more broadly. The mismatch between SDGs goals and targets and biodiversity and ecosystem services is more than an issue of semantics or monitoring. In fact, these gaps can lead to a range of unintended consequences that may jeopardise longer-term progress toward the SDGs. An incomplete understanding and ability to capture where and how trends in biodiversity and ecosystem services are jeopardising SDG attainment, risks marginalising their role in the SDGs. These gaps will lead to an inability to explore how trends in biodiversity and ecosystem services are having consequences for sustainable development in different geographies, understand where greater research is needed, and designate meaningful indicators and data sets[17] that can inform not only the SDGs, but also the CBD as it articulates a post-2020 global biodiversity framework. In addition, this could lead to deprioritising investment in biodiversity and ecosystem services restoration as part of investing in SDG target achievement. Without capturing the contribution of biodiversity and ecosystem services in sustainable development goals and targets, we risk being unable to create the necessary knowledge, acknowledge the stewardship necessary and rethink potential leverage points.

The SDGs are already in motion, with efforts to track progress to existing goals and their targets. However, the recently initiated CBD process to agree on a post-2020 global biodiversity framework (GBF) presents an opportune moment to more adequately capture biodiversity and ecosystem services'

contributions to sustainable development in the next generation of global biodiversity goals and targets. Such improvements could subsequently be linked to the accelerated actions of the final decade of the SDGs, as well as future iterations of the SDGs post-2030.

Below we follow Schlüter et al. (2019)'s SES analytical framework to organise a road map of suggested improvements that could be included in the post-2020 GBF[12]. We focus on improvements in the set of global targets of biodiversity and ecosystem services. These targets quantify the level of ambition for the higher level (often political) goals and frequently determine the set of indicators to be developed in the future. They present a useful entry point for better capturing the interdependencies between biodiversity, ecosystem service and sustainable development. Schlüter et al. (2019) suggest that an SES analytical framework addresses two gaps in current approaches to: (1) better capture the intertwined nature of social-ecological interactions; and to (2) better study the process of emergence of outcomes at the system level. We apply this analytical framework to the interdependencies of biodiversity, ecosystem services and the SDGs targets to help guide the future development of more integrated targets. Although we critique the current set of SDG targets, our aim is to inform the development of next-generation targets in the CBD post-2020 framework and related efforts, and thereby stimulate the identification of more fit-for-purpose indicators.

To simplify the discussion of findings and recommendations, we follow the SES-based approach to group SDGs into four clusters used in IPBES. These clusters place SDGs into: ecological; social-ecological, social and driver goals according to the nature of feedbacks between biodiversity, ecosystem services and the underlying targets of each SDG (Figure 2). These clusters are based on the wording of targets, not the broad goal-level intent, as the relationship to biodiversity and ecosystem services is more explicit in the ambition of the targets.

Moving to social-ecological targets

The ecological, social and, to some extent, social-ecological goal clusters include targets that are largely treated as separate social or ecological targets (Figure 2). This separation is prevalent in many areas of research and policy adopting either an ecocentric or anthropocentric view on sustainable development, which limits our ability to view sustainable development as a problem of inseparable social-ecological systems of continuously interacting and evolving components. This separation is also apparent in the IPBES conceptual framework[33] which depicts biodiversity, ecosystem services and human wellbeing as three separate boxes, rather than as an inseparable SES. Selomane et al. (2019) highlight that more than 70% of the SDG indicators are social indicators, while the IPBES Global Assessment found that only 29% of targets included some ecological aspect[18]. Future formulations of sustainable development goals, and their underlying targets and indicators would benefit from a greater focus on

integration and recognition of inherent interdependencies. This focus would not only support the desired policy coherence, a major motivation for the UN Agenda 2030, but also avoid the retrospective integration that is now occupying many researchers and governments[8]. A chief area of improvement should include moving from only ecological and social targets towards more integrated social-ecological targets (Figure 1; Figure 2). This would help make clear the social-ecological interconnections and interdependencies across all targets, with knock on effects at the indicator level. Below we outline two main recommendations for moving towards a greater degree of social-ecological integration in global targets.

Incorporate the support system role of biodiversity in sustainable development (ecological → social-ecological targets)

There is general evidence that biodiversity plays a support system role for sustainable development through its structures and functions supporting social and economic development, the provision of options and adaptive capacity for the future, and as a source of resilience in times of change [27 34 35]. Although the ecological cluster of targets broadly encompass biodiversity and ecosystem services in current target formulation, the focus is often vague and mostly on ecosystem extent or proportion of ecosystem protection, not making explicit how this links to supporting sustainable development (Table 2). A failure to make these connections is evident even in targets like SDG target 14.2, which focuses on sustainably managing and protecting marine and coastal ecosystems. The Great Barrier Reef has had an ecosystem-based approach in place for many years[36] and therefore under the current target most indicators would suggest positive trends in target achievement. However this would not capture the fact that the GBR has been repeatedly hit with mass coral bleaching,[37] severely compromising ecosystem integrity, function and resilience[37 38] with 30% of its reefs transformed by die-offs[39] and a predicted 89% drop in coral larval recruitment, impairing future recovery[40] and undermining the support system role that it plays in sustainable development.

Global targets that go beyond a focus on the *amount* of biodiversity, to specifically focus on functional changes in biodiversity relevant to sustainable development goals (e.g. ecosystem integrity, connectivity or health, functional diversity or other functional measures[35,41]) would be better suited to capture the support system aspects of biodiversity. A global target that specifically focused on ecosystem integrity relevant to sustainable development would support the devolution to governments of nationally relevant ecosystem integrity targets for implementation based on their relevant ecosystems and functions or services of concern. Recent advances in frameworks for capturing ecosystem integrity or health can facilitate the formulation of such targets. For example, the Ocean Health Index[42] framework identifies a number of variables of ecosystem health relative to meaningful reference points based on functional

relationships, time series, or spatial reference points[43]. Similarly, the Biodiversity Intactness Index, which captures changes in functional groups relevant to key ecosystem functions, is increasingly offering promise at global and national scales to feed into target-setting processes better able to capture the support system role of biodiversity[32,35].

In the critical area of climate change, the support system role of biodiversity is also not currently well integrated into global targets, missing the essential roles that biodiversity and ecosystem services play in climate actions. Such targets could include explicit levels of key ecosystem functions and services including carbon storage[44], local climate regime regulation[45,46], mitigating storms, sea-level rise[47], and drought[48], as well as the evolutionary potential for adaptation[35]. Area-based targets like Target 14.5, which aims to conserve 10 per cent of coastal and marine areas, are important. However, there is need for target-setting approaches that make explicit ecosystem functions and the differential functional capacities of ecosystems for these roles[49].

Account for ecosystem services in sustainable development (social and ecological → social-ecological targets)

Huge strides have been made in understanding, analysing and quantifying the benefits or ecosystem services provided by biodiversity to people[50,51]. In spite of these advances, few SDG targets are truly social-ecological targets that link the contributions of biodiversity and ecosystem services to development priorities such as poverty alleviation, health and food security (Figure 1; Figure 2). Even in the social-ecological goal cluster (Figure 2), the current formulation of targets largely results in implementation focusing on the social aspects of the target. For example SDG Target 1.5 aims to "build the resilience of the poor … to climate-related extreme events and other economic, social and environmental shocks and disasters". While biodiversity and ecosystem services have been shown to contribute to many facets of this target, the largely social formulation of the target has resulted in indicators of numbers of deaths, economic losses and risk reduction policies. Such targets result in implementation largely missing out on the vast data and knowledge linking ecosystem services to the target e.g. through their ability to absorb or buffer hazards (e.g. coastal ecosystem integrity[52]), or through their role in enhancing resilience of ecosystem services to these extreme events[53]. A target that explicitly recognises the role of biodiversity in reducing vulnerability, would direct implementation in new directions, conserving and restoring key ecosystems, their extent, condition and services.

Furthermore, there is a need to expand from ecological targets to social-ecological ecosystem service targets (Figure 1; Figure 2). For example, targets that go beyond ecosystem or species measures to stipulate slowing or halted rates of declines in a set of ecosystem services and their benefits to people would offer avenues for countries to adopt new approaches and data capturing trends in a set of

ecosystem services relevant to national priorities e.g. food production[54,55], poverty alleviation and vulnerability[56], health[57,58] or urbanisation[59]. Due to its integrated mission linking biodiversity, ecosystem services and human wellbeing, the post-2020 GBF is best placed to set such integrated social-ecological targets for biodiversity and the bundle of ecosystem services relevant to global and national sustainable development goals. Being clear that such targets must go beyond provisioning services, to include regulating services and intangible benefits from cultural services would also be important[1,33].

The social cluster of targets (Figure 2) almost entirely miss out on linkages to biodiversity and ecosystem services in the education, gender equality, equity and peace goals, where a growing evidence base suggests important linkages and feedbacks to goal achievement[60-63]. This underrepresentation of the role of biodiversity and ecosystem services in these goals is problematic as it will fail to capture the consequences of ecosystem changes for development more broadly e.g. the role of climate change and resource scarcity in conflict[64,65] or the positive feedbacks from gender empowerment in areas such as agricultural productivity[66] and fisheries[67,68]. Furthermore, such a separation limits more integrated approaches in areas such as health, equality, education and peace-building, limiting effective management and policies for development. Future global targets that better integrate the multiple values of tangible and intangible benefits linking biodiversity and sustainable development[69] would ensure progress towards maintaining the overall cultural and functional aspects of biodiversity and ecosystem services that people rely on.

Social-ecological feedbacks and emergent outcomes

Biodiversity lies at the heart of key feedbacks driving emergent outcomes of sustainable development (Figure 1), but very few of these feedbacks and their macro-level impacts are visible in current targets and monitoring efforts. Tracking feedbacks, identifying and making hidden feedbacks visible, and shifting or reconfiguring feedbacks will be central to sustainable development, and will further emphasise the constant and dynamic interdependencies of social and ecological elements at the core of an indivisible sustainable development imperative. We suggest two recommendations for future global targets to better capture and reveal these feedbacks underlying sustainable development outcomes.

Capture feedbacks reinforcing biodiversity loss and (un)sustainable outcomes

Current SDG targets are disappointing in their treatment of key biodiversity feedbacks, even in obvious areas such as climate change and food production (Figure 2). Both of these areas of sustainable development are major drivers of biodiversity loss[39], but are also areas where biodiversity loss will have serious implications[35]. Biodiversity loss has important reinforcing feedbacks across many ecosystem, earth system and biogeochemical variables including greenhouse gas emissions, nitrogen and phosphate

cycles and hydrological cycles essential for maintaining a stable earth system[34]. In addition, there are important feedbacks between biodiversity loss and multiple ecological functions and ecosystem services essential to sustainable development[35,70-73]. Feedbacks that drive biodiversity loss e.g. climate changes, eutrophication, habitat fragmentation[74] have cascading and often indirect effects on poverty, hunger and other goals[75] and are largely missing or obscured in current targets. Similarly, negative biodiversity feedbacks, where biodiversity may have negative impacts on human health including vector-borne diseases, must also be considered[76].

One potential avenue to address these gaps would include the setting of targets that explicitly focus on the reinforcing or dampening feedbacks of biodiversity loss. For example, targets 14.3 to reduce the impacts of ocean acidification and 15.3 on combatting desertification, focus on the outcomes of multiple feedbacks linking biodiversity loss and climate change. To be effective, targets such as these need to be more clearly linked to the greenhouse gases and land-use feedbacks responsible for these outcomes, as well as the reinforcing feedbacks between degradation and acidification, biodiversity loss, and sustainable development. A target that links CO_2 emissions, acidification, ocean ecosystems and their services[77] would more adequately focus attention on key feedbacks and outcomes for sustainable development. It would also leads to the development of indicators of all of components, rather than the currently limited indicators of marine acidity and proportion of degraded area under these targets.

Examples like these open up the potential to go beyond reformulating targets to reconfiguring the design of the whole system of global targets (Figure 1). The separation of goals and targets into sectors, or into the linear categories of causes (drivers), state and responses, as is often the case in global targets, is a key obstacle to detecting and managing the feedbacks associated with biodiversity loss. A prime example is the hunger goal where the juxtaposition of ecological vs. social targets hides the social-ecological feedbacks between these and has proven problematic to implement. For example Target 2.3 aims to double the agricultural productivity and incomes of small-scale food producers while Target 2.4 ensures sustainable food production systems and implements resilient agricultural practices. Agricultural productivity, ecosystem sustainability and resilience are linked in dynamic ways by biodiversity feedbacks[53]. Furthermore, these targets could be said to focus attention on the wrong things, rather than aspects such as trade, access, food waste, cultural values, and farming livelihoods[78], which result in feedbacks over space and time, but are ignored in the current targets set under the hunger goal.

This challenge could be said to represent a microcosm of the whole SDG target set, and arguably other global target frameworks in existence. One potential route for future policy frameworks, including the post-2020 GBF, would be to redesign this set of targets using a social-ecological systems approach (Figure 1). For example, depicting the hunger goal as a social-ecological system of food and nutrition security (and quality) within the economic, social, and environmental dimensions of the multifunctional

food system, would enable the identification of key feedbacks and emergent outcomes of relevance for further target setting. This is not to suggest that a target set representing the entire food system is required, but rather that an awareness of the social-ecological food system is required before targets can be set. From such an understanding of key processes, feedbacks and determinants of food security, a target framework, such as the post-2020 GBF, could prioritise targets relevant to biodiversity, including levers of change in the food system required to conserve and restore biodiversity. Much of this work depicting complex food systems has already been advanced for the global food system[79] as well as national food systems[78], as well as for many other systems relevant to sustainable development (e.g. energy, water), offering a rich resource from which to identify relevant targets at global as well as national scales. A further advantage of such an approach to the system of targets is an increased ability to capture the key social-ecological feedbacks and dynamics behind some of the emergent sustainable development challenges such as poverty traps[80], persistent food insecurity and inequality[21] and other patterns of marginalisation and vulnerability at the heart of development efforts (Figure 1).

Reveal missing feedbacks linking sustainable development, biodiversity and ecosystem services

The driver cluster (Figure 2) encompasses goals and targets on energy, economic growth, consumption and infrastructure that could play a large role in driving system changes, including biodiversity and ecosystem service declines, with feedbacks to other areas of sustainable development. However, determining the nature and extent of these impacts and their feedbacks depends on the pathways taken to achieve these goals. Capturing these feedbacks is currently a major gap in the driver targets (Table 2). For example, increased renewable energy development (target 7.2) has the capacity for slowing impacts on biodiversity loss caused by fossil fuel energy use, by mitigating climate change, air and water pollution, and mining. However, renewable hydropower can also have major feedback effects on biodiversity in freshwater systems[81,82] and additional feedbacks to goals related to poverty, hunger, and clean water by affecting water quality and quantity for food production and development[83,84]. Many of these potential feedbacks are linked to negative or unintended (or undervalued) consequences on biodiversity and ecosystem services. The feedbacks need to be more explicit in target-setting and indicator development for the driver goals[85-87]. Targets and subsequent indicators that make these potential risks and feedbacks clear would be needed to ensure mitigation measures are implemented, not only for biodiversity and ecosystem services, but also for vulnerable and marginalised communities who may be disproportionately impacted by energy, infrastructure, growth and consumption. Critically, the approach to achieving these targets must also be made clearer. Here not only is the target of relevance, but also the procedures taken to achieve the target at national scales. Ensuring fair and just, multi-sectoral participation in the determination of many of these targets, and the options and pathways to target

achievement, will be key to mitigate negative feedbacks and outcomes at national, as well as global scales.

In a similar fashion to the recommendation above, one of the most important avenues to reveal the feedbacks involved in the driver goals, would involve revisions to the whole system of goals and targets (Figure 1). While good progress has been made in multiple-scale targets capturing separate national and global scales, these target systems still mask feedback signals from cross-scale dynamics of SESs (Reyers et al. 2018) (Figure 1). These cross-scale feedbacks do not align with the political scales of global targets nor with the additive scalar assumptions inherent in these targets.

The trade and movement of water resources is an example of such cross-scale dynamics. Several countries rely on foreign water resources to meet their needs, while others can have major impacts on water consumption and pollution in other regions through their water use. Furthermore recent work modelling social-ecological connections linking land use change and rainfall effects illustrate their transcontinental dynamics linking rainfall in far distant countries[72,88]. These patterns are deeply embedded with food production and irrigation[89,90], suggesting that decisions about agricultural production as part of the hunger goal will have strong emergent connections that may impact biodiversity and ecosystem services elsewhere, with cascading effects on poverty, economic growth or inequalities at other temporal or spatial scales[83]. Such cross-scale dynamics demand that future policy frameworks design new systems of global targets and indicators with which to capture these currently unreported dynamics, to better direct attention, action and monitoring to the spatial and temporal scales of the feedbacks shaping sustainable development.

At the global level, new targets which focus attention on such regional and continental interdependencies are one potential way forward. For example, a target on fisheries (or other natural resource sectors) that focuses on improving traceability and tracking changing trade structures and consolidation would complement the current target focus on trends in national or global fisheries stocks (Target 14.4) or on reducing illegal activities (Target 14.6). Together, these targets would more comprehensively capture the telecoupled social-ecological feedbacks and dynamics currently dominating fisheries[91].

Furthermore, recent global changes in the international corporate and financial structures[92], as well as increased global trade[16], now creates unprecedented connections, feedbacks and risks to biodiversity and sustainable development across biomes and regions. Global targets more responsive to the roles played by e.g. international financial actors in large-scale deforestation and biome tipping points[92] or consolidation trends of transnational corporations who dominate fisheries, greenhouse gas emissions, and food production[93] are required to focus attention and track these changes in global and cross-scale dynamics driving biodiversity loss and its sustainable development feedbacks across large

scales. Currently this is a critical gap in biodiversity targets, requiring new cross-sectoral and –scalar approaches[69,91] for managing and monitoring these feedbacks and their outcomes for sustainable development (Figure 1).

CBD post-2020 and future sustainable development targets

With accruing evidence of recent increases in hunger, globalising inequalities and entrenched and emerging patterns of marginalisation and extreme poverty, together with declines in biodiversity and ecosystem services[94], the myth of a choice between environment and development is exposed for the false choice that it has become. In fact as IPBES[1] and Secretary General's report on the Progress toward the SDGs[94] reveal, we are currently following a global development trajectory that is bad for the environment and for the well-being of many, if not most people[1].

Development at the cost of biodiversity and ecosystem services is not a choice, but rather an inaccurate snapshot which obscures the interconnected complex and dynamic nature of the world, deferring consequences to other places and to future generations. We are clearly in need of a new vision of sustainable development able to capture its complex realities to reveal these impacts and challenge these apparent choices. Agenda 2030 took an important first step in this direction, but the political realities of sectoralised goals have limited its ability to capture the indivisible interdependencies of biodiversity, ecosystem services, and sustainable development[95]. As one of the first policy windows to tackle this challenge, the CBD post-2020 GBF can benefit from lessons being realised in SDG reporting, as well as assessments such as IPBES and the gaps they are revealing. By making clearer how biodiversity and ecosystem services matter to sustainable development, this framework can set the baseline for and promote greater policy coherence by presenting a framework that is built around the intertwined nature of biodiversity and sustainable development.

We propose four recommendations emerging from a social-ecological systems view of biodiversity and sustainable development. Principally, these recommendations suggest that in addition to ambitious targets on the multiple dimensions of biodiversity, there is also a need to move beyond the separation of ecological and social targets to set social-ecological targets that incorporate the key interdependencies between biodiversity, ecosystem services and sustainable development. These include making the support system role of biodiversity and the contribution of ecosystem services explicit in all aspects and targets of sustainable development. Furthermore, these recommendations highlight the need for targets that reveal feedbacks at the heart of sustainable development challenges. Such targets will challenge assumptions of sectoral and scalar separability[95], but offer promise for new systems of global targets more accurately accounting for biodiversity and ecosystem services in development. Greater movement on these recommendations as well as recent advances in scientific understanding and data

make the promise of an interconnected and indivisible sustainable development agenda more readily achievable.

Conclusion

A focus on goals, target and indicators is only a small part of sustainable development, which also requires actions including transformative changes in the systems and structures of development[1]. Biodiversity and ecosystem services are not only on the receiving end of these transformative changes, but also key components or foundations of the transformative changes needed to move towards more sustainable and equitable futures[1]. These changes will require reconnections and reconfigurations of social-ecological relationships acknowledging and accounting for the role of biodiversity and ecosystem services in development across space and time[96,97]. Meeting these challenges has the opportunity to create coherent systems of global targets that truly recognise the foundational, but complex role that biodiversity and ecosystem services play in sustainable development policy and practice, highlighting the "whole system" nature of sustainable development.

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Table 1. Relevant international agreements, global goals and targets, as well as intergovernmental bodies for biodiversity, ecosystem services and sustainable development

Name	Year	Description and objectives
Convention on Biological Diversity (CBD)	1993	International treaty under the United Nations Environmental Programme (UNEP) for the conservation of biological diversity, the sustainable use of the components of biological diversity, and the fair and equitable sharing of the benefits arising out of the utilisation of genetic resources.
Strategic Plan for Biodiversity 2011-2020 and Aichi Targets	2010	The Parties to the CBD adopted the Strategic Plan for Biodiversity 2011-2020 guided by a 2050 vision of "Living in Harmony with Nature" which states that "By 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people." The vision was translated into a set of 5 goals and 20 targets, called the Aichi Biodiversity Targets for the period 2011-2020.
Post-2020 Global Biodiversity Framework	2020	The CBD will adopt a post-2020 global biodiversity framework as the next stepping stone towards the 2050 Vision of "Living in harmony with nature". The Parties to the CBD have adopted a participatory process for the preparation of the framework, and its goals and targets, with ongoing consultation until the Conference of the Parties in October 2020
The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services	2012	The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) is an independent intergovernmental body established to strengthen the interface between the scientific community and policy makers with the aim to enhance the use of science in policy making for the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development. As part of its functions, it performs regular and timely assessments of knowledge on biodiversity and ecosystem services, which include thematic, global and regional assessments. Eight such assessments have been completed, including the Global Assessment referred to here.
Agenda 2030 and the Sustainable Development Goals (SDG)	2015	The UN adopted the 2030 Agenda for Sustainable Development, which includes 17 Sustainable Development Goals (SDGs) and 169 targets under these goals. Figure 2 contains a list of these goals. For full details on the targets: https://unstats.un.org/sdgs/indicators/Global%20Indicator%20Framework%20after%202020%20review_Eng.pdf

Table 2. Roadmap and recommendations for future global targets based on an SES analytical framework[12]. The recommendations aim to better capture the contribution of biodiversity and ecosystem services to sustainable development in future targets. Goal clusters are those outlined in Figure 2.

Roadmap	Recommendation	Goal cluster	Current focus	Advances needed	Illustrative examples of possible ways forward
4.1 Capturing intertwined social-ecological interdependencies and feedbacks	Integrate the support system role of biodiversity in sustainable development *Ecological -> Social-ecological targets*	Ecological goals	Targets biased towards amounts (quantities) of biodiversity e.g. abundance or species richness which don't capture the support role of biodiversity to sustainable development	Targets required that capture relevant functional aspects (qualities) of biodiversity e.g. ecosystem integrity, intactness of functional groups, functional diversity.	Target setting using frameworks such as Ocean Health Index[43] or Biodiversity Intactness Index[32,35] that focus on ecosystem condition relative to management goals or functional aspects of biodiversity relevant to sustainable development Targets that recognise the functional capacities of ecosystems in climate mitigation[49]
	Account for ecosystem services in sustainable development *Social and ecological → social-ecological targets*	Social-ecological goals	Targets do not clearly acknowledge the role of biodiversity or ecosystems services in these goals. Targets are only focused on social dimensions.	Targets that explicitly acknowledge the role of biodiversity in development goals Targets that account for required levels of ecosystem services including regulating and cultural services	A target that explicitly recognises the role of biodiversity and ecosystem services in reducing vulnerability to extreme climate events[52] Targets of rates of declines in key regulating services

		Social goals	Current targets focus only on social dimensions of these goals with no reference to the role of biodiversity or ecosystem services	Targets are required that are built on more integrated approaches to social goals acknowledging their social-ecological interdependencies	relevant to social-ecological goals (e.g. hunger) There is a need for research to help formulate targets that capture the role of biodiversity and ecosystem services in these goals in areas such as climate change and conflict, inequality and ecosystem change, and health and biodiversity loss.
4.2 Capture and reveal social-ecological feedbacks driving sustainable development outcomes	Capture feedbacks reinforcing biodiversity loss and unsustainable outcomes	Ecological goals Social-ecological goals	Targets separated into either social or ecological and fail to capture feedbacks between biodiversity loss and goals even in obvious areas like the climate and hunger goals	Targets that focus on feedbacks of biodiversity loss Revisions to the whole system of targets to adopt a SES approach to identify relevant targets	A target that links CO_2 emissions, ocean acidification and impacts on biodiversity and ecosystem services[77] Adopting a SES food system[98] approach for the hunger goal to identify targets of key feedbacks and leverage points relevant to biodiversity
	Reveal missing feedbacks linking biodiversity, ecosystem services and sustainable development	Driver goals	Targets are vague and don't make explicit the feedbacks to biodiversity and ecosystem services (and other sectors of society) Current global and national scale focus ignores important cross-scale social-ecological feedbacks	Targets are required that make clear potential risks and impacts to other sectors including biodiversity and ecosystem services Revisions to the whole system of targets to better account for feedbacks especially those that are cross-scale	Targets that track the impact of renewable energy development on biodiversity and ecosystem services[84] A global target for fisheries that focuses on improving traceability and tracking changing trade structures[91]

Figure captions

Figure 1. A complex social-ecological systems (SES) approach to the analysis of social-ecological interdependencies and feedbacks between biodiversity, ecosystem services and sustainable development. The analysis is depicted at two levels suggested by Schlüter et al. (2019): the subsystem-level of social, ecological and social-ecological dynamics[99], and the macro- or system-level of emergent outcomes.

Figure 2. Goal clusters which summarise the findings of the IPBES global assessment on the consequences of biodiversity and ecosystem service trends for SDG achievement. Percentages in parentheses are calculated from the number of targets assessed and rounded to nearest significant digit. Goal 17 was not included. Dashed lines indicate uncertainty about possible feedbacks due to current target wording and omissions.

References

1   Díaz, S. *et al.* Pervasive human-driven decline of life on Earth points to the need for transformative change. *Science* **366**, eaax3100, doi:10.1126/science.aax3100 (2019).

2   Anderson, C. B. *et al.* Determining nature's contributions to achieve the sustainable development goals. *Sustainability Science* **14**, 543-547, doi:10.1007/s11625-018-0643-5 (2019).

3   Wood, S. L. R. *et al.* Distilling the role of ecosystem services in the Sustainable Development Goals. *Ecosystem Services* **29**, 70-82, doi:https://doi.org/10.1016/j.ecoser.2017.10.010 (2018).

4   United Nations. Report of the Secretary-General on SDG Progress 2019 (United Nations, New York, 2019).

5   Le Blanc, D. Towards Integration at Last? The Sustainable Development Goals as a Network of Targets. *Sustainable Development* **23**, 176-187, doi:10.1002/sd.1582 (2015).

6   United Nations. Tranforming our World: the 2030 Agenda for Sustainable Development. (United Nations, New York, 2015).

7   McGowan, P. J. K., Stewart, G. B., Long, G. & Grainger, M. J. An imperfect vision of indivisibility in the Sustainable Development Goals. *Nature Sustainability* **2**, 43-45, doi:10.1038/s41893-018-0190-1 (2019).

8   Nilsson, M., Griggs, D. & Visbeck, M. Policy: Map the interactions between sustainable development goals. *Nature* **534**, 320-322 (2016).

9   Barbier, E. B. & Burgess, J. C. The Sustainable Development Goals and the systems approach to sustainability. *Economics: The Open-Access, Open-Assessment E-Journal* **11**, 1-22 (2017).

10   Nilsson, M. *et al.* Mapping interactions between the sustainable development goals: lessons learned and ways forward. *Sustainability Science* **13**, 1489-1503, doi:10.1007/s11625-018-0604-z (2018).

11   Nerini, F. F. *et al.* Mapping synergies and trade-offs between energy and the Sustainable Development Goals. *Nature Energy* **3**, 10-15, doi:10.1038/s41560-017-0036-5 (2018).

12   Schlüter, M. *et al.* Capturing emergent phenomena in social-ecological systems: an analytical framework. *Ecology and Society* **24**, doi:10.5751/ES-11012-240311 (2019).

13   Preiser, R., Biggs, R., De Vos, A. & Folke, C. Social-ecological systems as complex adaptive systems: organizing principles for advancing research methods and approaches. *Ecology and Society* **23**, doi:10.5751/es-10558-230446 (2018).

14   Fischer, J. *et al.* Advancing sustainability through mainstreaming a social-ecological systems perspective. *Current Opinion in Environmental Sustainability* **14**, 144-149, doi:10.1016/j.cosust.2015.06.002 (2015).

15   Leslie, H. M. *et al.* Operationalizing the social-ecological systems framework to assess sustainability. *Proceedings of the National Academy of Sciences of the United States of America* **112**, 5979-5984, doi:10.1073/pnas.1414640112 (2015).

16   Reyers, B., Folke, C., Moore, M.-L., Biggs, R. & Galaz, V. Social-Ecological Systems Insights for Navigating the Dynamics of the Anthropocene. *Annual Review of Environment and Resources* **43**, 267-289, doi:10.1146/annurev-environ-110615-085349 (2018).

17   Reyers, B., Stafford-Smith, M., Erb, K. H., Scholes, R. J. & Selomane, O. Essential Variables help to focus Sustainable Development Goals monitoring. *Current Opinion in Environmental Sustainability* **26-27**, 97-105, doi:10.1016/j.cosust.2017.05.003 (2017).

18   Selomane, O., Reyers, B., Biggs, R. & Hamann, M. Harnessing Insights from Social-Ecological Systems Research for Monitoring Sustainable Development. *Sustainability* **11**, doi:10.3390/su11041190 (2019).

19   Carpenter, S. R. *et al.* Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. *Proceedings of the National Academy of Sciences of the United States of America* **106**, 1305-1312, doi:10.1073/pnas.0808772106 (2009).

20   Berkes, F. Environmental Governance for the Anthropocene? Social-Ecological Systems, Resilience, and Collaborative Learning. *Sustainability* **9**, doi:10.3390/su9071232 (2017).

21   Leach, M. *et al.* Equity and sustainability in the Anthropocene: a social–ecological systems perspective on their intertwined futures. *Global Sustainability* **1**, e13, doi:10.1017/sus.2018.12 (2018).

22   Blythe, J., Nash, K., Yates, J. & Cumming, G. Feedbacks as a bridging concept for advancing transdisciplinary sustainability research. *Current Opinion in Environmental Sustainability* **26-27**, 114-119, doi:https://doi.org/10.1016/j.cosust.2017.05.004 (2017).

23   Takeuchi, K., Ichikawa, K. & Elmqvist, T. Satoyama landscape as social-ecological system: historical changes and future perspective. *Current Opinion in Environmental Sustainability* **19**, 30-39, doi:10.1016/j.cosust.2015.11.001 (2016).

24   Lafuite, A.-S. & Loreau, M. Time-delayed biodiversity feedbacks and the sustainability of social-ecological systems. *bioRxiv*, 112730, doi:10.1101/112730 (2017).

25   Daw, T. M. *et al.* Evaluating taboo trade-offs in ecosystems services and human well-being. *Proceedings of the National Academy of Sciences* **112**, 6949-6954, doi:10.1073/pnas.1414900112 (2015).

26   Liu, J. G. *et al.* Framing Sustainability in a Telecoupled World. *Ecology and Society* **18**, doi:10.5751/es-05873-180226 (2013).

27   Biggs, R. *et al.* Toward Principles for Enhancing the Resilience of Ecosystem Services. *Annual Review of Environment and Resources* **37**, 421-448, doi:10.1146/annurev-environ-051211-123836 (2012).

28   Haider, L. J., Boonstra, W. J., Peterson, G. D. & Schlüter, M. Traps and sustainable development in rural areas: a review. *World Development* **101**, 311-321 (2019).

29   Lade, S. J., Haider, L. J., Engstrom, G. & Schluter, M. Resilience offers escape from trapped thinking on poverty alleviation. *Science Advances* **3**, doi:10.1126/sciadv.1603043 (2017).

30   Rocha, J. C., Peterson, G., Bodin, O. & Levin, S. Cascading regime shifts within and across scales. *Science* **362**, 1379-+, doi:10.1126/science.aat7850 (2018).

31   Synes, N. W. *et al.* Coupled land use and ecological models reveal emergence and feedbacks in socio-ecological systems. *Ecography* **42**, 814-825, doi:10.1111/ecog.04039 (2019).

32   Mace, G. M. *et al.* Aiming higher to bend the curve of biodiversity loss. *Nature Sustainability* **1**, 448-451, doi:10.1038/s41893-018-0130-0 (2018).

33   Diaz, S. *et al.* The IPBES Conceptual Framework - connecting nature and people. *Current Opinion in Environmental Sustainability* **14**, 1-16, doi:10.1016/j.cosust.2014.11.002 (2015).

34   Steffen, W. *et al.* Planetary boundaries: Guiding human development on a changing planet. *Science* **347**, doi:10.1126/science.1259855 (2015).

35   Mace, G. M. *et al.* Approaches to defining a planetary boundary for biodiversity. *Global Environmental Change-Human and Policy Dimensions* **28**, 289-297, doi:10.1016/j.gloenvcha.2014.07.009 (2014).

36   Smith, D. C. *et al.* Implementing marine ecosystem-based management: lessons from Australia. *Ices Journal of Marine Science* **74**, 1990-2003, doi:10.1093/icesjms/fsx113 (2017).

37   Hughes, T. P. *et al.* Global warming and recurrent mass bleaching of corals. *Nature* **543**, 373-377, doi:10.1038/nature21707 (2017).

38   Hughes, T. P. *et al.* Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. *Science* **359**, 80-+, doi:10.1126/science.aan8048 (2018).

39   Hughes, T. P. *et al.* Global warming transforms coral reef assemblages. *Nature* **556**, 492-+, doi:10.1038/s41586-018-0041-2 (2018).

40   Hughes, T. P. *et al.* Global warming impairs stock–recruitment dynamics of corals. *Nature* **568**, 387-390, doi:10.1038/s41586-019-1081-y (2019).

41   Manning, P. *et al.* Redefining ecosystem multifunctionality. *Nature Ecology & Evolution* **2**, 427-436, doi:10.1038/s41559-017-0461-7 (2018).

42   Halpern, B. S. *et al.* An index to assess the health and benefits of the global ocean. *Nature* **488**, 615-620, doi:http://www.nature.com/nature/journal/v488/n7413/abs/nature11397.html (2012).

43   Samhouri, J. F. *et al.* Sea sick? Setting targets to assess ocean health and ecosystem services. *Ecosphere* **3**, art41, doi:10.1890/es11-00366.1 (2012).

44   Griscom, B. W. *et al.* Natural climate solutions. *Proceedings of the National Academy of Sciences* **114**, 11645-11650, doi:10.1073/pnas.1710465114 (2017).

45   McAlpine, C. A. *et al.* Forest loss and Borneo's climate. *Environmental Research Letters* **13**, 044009, doi:10.1088/1748-9326/aaa4ff (2018).

46   Prevedello, J. A., Winck, G. R., Weber, M. M., Nichols, E. & Sinervo, B. Impacts of forestation and deforestation on local temperature across the globe. *PLOS ONE* **14**, e0213368, doi:10.1371/journal.pone.0213368 (2019).

47   Arkema, K. K. *et al.* Coastal habitats shield people and property from sea-level rise and storms. *Nature Clim. Change* **3**, 913-918 (2013).

48   Nel, J. L. *et al.* Natural Hazards in a Changing World: A Case for Ecosystem-Based Management. *PLOS ONE* **9**, e95942, doi:10.1371/journal.pone.0095942 (2014).

49   Howard, J. *et al.* Clarifying the role of coastal and marine systems in climate mitigation. *Frontiers in Ecology and the Environment* **15**, 42-50, doi:10.1002/fee.1451 (2017).

50   Guerry, A. D. *et al.* Natural capital and ecosystem services informing decisions: From promise to practice. *Proceedings of the National Academy of Sciences of the United States of America* **112**, 7348-7355, doi:10.1073/pnas.1503751112 (2015).

51   Chaplin-Kramer, R. *et al.* Global modeling of nature's contributions to people. *Science* **366**, 255-258, doi:10.1126/science.aaw3372 (2019).

52   Arkema, K. K. *et al.* Embedding ecosystem services in coastal planning leads to better outcomes for people and nature. *Proceedings of the National Academy of Sciences* **112**, 7390-7395, doi:10.1073/pnas.1406483112 (2015).

53   Isbell, F. *et al.* Biodiversity increases the resistance of ecosystem productivity to climate extremes. *Nature* **526**, 574-577, doi:10.1038/nature15374 (2015).

54   Garbach, K. *et al.* Examining multi-functionality for crop yield and ecosystem services in five systems of agroecological intensification. *International Journal of Agricultural Sustainability* **15**, 11-28, doi:10.1080/14735903.2016.1174810 (2017).

55   Wood, S. A. *et al.* Functional traits in agriculture: agrobiodiversity and ecosystem services. *Trends in Ecology & Evolution* **30**, 531-539, doi:10.1016/j.tree.2015.06.013 (2015).

56   Schreckenberg, K., Mace, G. & Poudyal, M.   352 (Routledge, London, 2018).

57   Whitmee, S. *et al.* Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health. *The Lancet* **386**, 1973-2028, doi:10.1016/S0140-6736(15)60901-1 (2015).

58   Buckley, R. C. & Brough, P. Economic Value of Parks via Human Mental Health: An Analytical Framework. *Frontiers in Ecology and Evolution* **5**, doi:10.3389/fevo.2017.00016 (2017).

59   Elmqvist, T. *et al. Urban Planet: Knowledge towards Sustainable Cities*. (Cambridge University Press, 2018).

60   Daskin, J. H. & Pringle, R. M. Warfare and wildlife declines in Africa's protected areas. *Nature* **553**, 328-+, doi:10.1038/nature25194 (2018).

61   von Uexkull, N., Croicu, M., Fjelde, H. & Buhaug, H. Civil conflict sensitivity to growing-season drought. *Proceedings of the National Academy of Sciences* **113**, 12391-12396, doi:10.1073/pnas.1607542113 (2016).

62   Moss, A., Jensen, E. & Gusset, M. Impact of a global biodiversity education campaign on zoo and aquarium visitors. *Frontiers in Ecology and the Environment* **15**, 243-247, doi:10.1002/fee.1493 (2017).

63   Rustad, S. A. & Binningsbo, H. M. A price worth fighting for? Natural resources and conflict recurrence. *Journal of Peace Research* **49**, 531-546, doi:10.1177/0022343312444942 (2012).

64   Linke, A. M., Witmer, F. D. W., O'Loughlin, J., McCabe, J. T. & Tir, J. The consequences of relocating in response to drought: human mobility and conflict in contemporary Kenya. *Environmental Research Letters* **13**, doi:10.1088/1748-9326/aad8cc (2018).

65   Burrows, K. & Kinney, P. Exploring the Climate Change, Migration and Conflict Nexus. *International Journal of Environmental Research and Public Health* **13**, 443 (2016).

66   UNEP. Global Gender and Development Outlook. (United Nations Environment Programme, Nairobi, 2016).

67   Harper, S., Grubb, C., Stiles, M. & Sumaila, U. R. Contributions by Women to Fisheries Economies: Insights from Five Maritime Countries. *Coastal Management* **45**, 91-106, doi:10.1080/08920753.2017.1278143 (2017).

68   Cole, S. M. *et al.* Postharvest fish losses and unequal gender relations: drivers of the social-ecological trap in the Barotse Floodplain fishery, Zambia. *Ecology and Society* **23**, doi:10.5751/es-09950-230218 (2018).

69   Martin-Lopez, B., Gomez-Baggethun, E., Garcia-Llorente, M. & Montes, C. Trade-offs across value-domains in ecosystem services assessment. *Ecological Indicators* **37**, 220-228, doi:10.1016/j.ecolind.2013.03.003 (2014).

70   Carpenter, S. R. & Bennett, E. M. Reconsideration of the planetary boundary for phosphorus. *Environmental Research Letters* **6**, doi:10.1088/1748-9326/6/1/014009 (2011).

71   Cardinale, B. J. *et al.* Biodiversity loss and its impact on humanity. *Nature* **486**, 59-67, doi:10.1038/nature11148 (2012).

72   Keys, P. W., Wang-Erlandsson, L. & Gordon, L. J. Megacity precipitationsheds reveal tele-connected water security challenges. *PLOS ONE* **13**, e0194311, doi:10.1371/journal.pone.0194311 (2018).

73   Dakos, V. *et al.* Ecosystem tipping points in an evolving world. *Nature Ecology & Evolution* **3**, 355-362, doi:10.1038/s41559-019-0797-2 (2019).

74   Pardini, R., Bueno, A. d. A., Gardner, T. A., Prado, P. I. & Metzger, J. P. Beyond the Fragmentation Threshold Hypothesis: Regime Shifts in Biodiversity Across Fragmented Landscapes. *PLOS ONE* **5**, e13666, doi:10.1371/journal.pone.0013666 (2010).

75   Rocha, J. C., Peterson, G., Bodin, Ö. & Levin, S. Cascading regime shifts within and across scales. *Science* **362**, 1379-1383, doi:10.1126/science.aat7850 (2018).

76   Oosterbroek, B., de Kraker, J., Huynen, M. & Martens, P. Assessing ecosystem impacts on health: A tool review. *Ecosystem Services* **17**, 237-254, doi:10.1016/j.ecoser.2015.12.008 (2016).

77   Gattuso, J.-P. *et al.* Contrasting futures for ocean and society from different anthropogenic CO_2 emissions scenarios. *Science* **349**, aac4722, doi:10.1126/science.aac4722 (2015).

78   Pereira, L. & Drimie, S. Governance Arrangements for the Future Food System: Addressing Complexity in South Africa. *Environment: Science and Policy for Sustainable Development* **58**, 18-31, doi:10.1080/00139157.2016.1186438 (2016).

79   Ericksen, P. J. Conceptualizing food systems for global environmental change research. *Global Environmental Change* **18**, 234-245, doi:https://doi.org/10.1016/j.gloenvcha.2007.09.002 (2008).

80   Lade, S. J., Haider, L. J., Engström, G. & Schlüter, M. Resilience offers escape from trapped thinking on poverty alleviation. *Science Advances* **3**, e1603043, doi:10.1126/sciadv.1603043 (2017).

81   Winemiller, K. O. *et al.* Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong. *Science* **351**, 128-129, doi:10.1126/science.aac7082 (2016).

82   Grill, G. *et al.* Mapping the world's free-flowing rivers. *Nature* **569**, 215-+, doi:10.1038/s41586-019-1111-9 (2019).

83   Beck, M. W., Claassen, A. H. & Hundt, P. J. Environmental and livelihood impacts of dams: common lessons across development gradients that challenge sustainability. *International Journal of River Basin Management* **10**, 73-92, doi:10.1080/15715124.2012.656133 (2012).

84   Botelho, A., Ferreira, P., Lima, F., Pinto, L. M. C. & Sousa, S. Assessment of the environmental impacts associated with hydropower. *Renewable and Sustainable Energy Reviews* **70**, 896-904, doi:https://doi.org/10.1016/j.rser.2016.11.271 (2017).

85   Barber, C. P., Cochrane, M. A., Souza, C. M. & Laurance, W. F. Roads, deforestation, and the mitigating effect of protected areas in the Amazon. *Biological Conservation* **177**, 203-209, doi:10.1016/j.biocon.2014.07.004 (2014).

86   Benitez-Lopez, A., Alkemade, R. & Verweij, P. A. The impacts of roads and other infrastructure on mammal and bird populations: A meta-analysis. *Biological Conservation* **143**, 1307-1316, doi:10.1016/j.biocon.2010.02.009 (2010).

87   Driscoll, D. A. *et al.* A biodiversity-crisis hierarchy to evaluate and refine conservation indicators. *Nature Ecology & Evolution* **2**, 775-781, doi:10.1038/s41559-018-0504-8 (2018).

88   Hoekstra, A. Y. & Mekonnen, M. M. The water footprint of humanity. *Proceedings of the National Academy of Sciences of the United States of America* **109**, 3232-3237, doi:10.1073/pnas.1109936109 (2012).

89   Dalin, C., Wada, Y., Kastner, T. & Puma, M. J. Groundwater depletion embedded in international food trade. *Nature* **543**, 700-+, doi:10.1038/nature21403 (2017).

90   D'Odorico, P. *et al.* Global virtual water trade and the hydrological cycle: patterns, drivers, and socio-environmental impacts. *Environmental Research Letters* **14**, doi:10.1088/1748-9326/ab05f4 (2019).

91   Crona, B. I. *et al.* Masked, diluted and drowned out: how global seafood trade weakens signals from marine ecosystems. *Fish. Fish.* **17**, 1175-1182, doi:10.1111/faf.12109 (2016).

92   Galaz, V. *et al.* Tax havens and global environmental degradation. *Nature Ecology & Evolution* **2**, 1352-1357, doi:10.1038/s41559-018-0497-3 (2018).

93   Folke, C. *et al.* Transnational corporations and the challenge of biosphere stewardship. *Nature Ecology & Evolution* **3**, 1396-1403, doi:10.1038/s41559-019-0978-z (2019).

94   Secretary-General, U. Progress towards the Sustainable Development Goals : report of the Secretary-General. (UN, New York, 2018).

95   Stafford-Smith, M. *et al.* Integration: the key to implementing the Sustainable Development Goals. *Sustainability Science* **12**, 911-919, doi:10.1007/s11625-016-0383-3 (2017).

96   Abson, D. J. *et al.* Leverage points for sustainability transformation. *Ambio* **46**, 30-39, doi:10.1007/s13280-016-0800-y (2017).

97   Sachs, J. D. *et al.* Six Transformations to achieve the Sustainable Development Goals. *Nature Sustainability* **2**, 805-814, doi:10.1038/s41893-019-0352-9 (2019).

98   Eakin, H. *et al.* Identifying attributes of food system sustainability: emerging themes and consensus. *Agriculture and Human Values* **34**, 757-773, doi:10.1007/s10460-016-9754-8 (2017).

99   Biggs, R., Schlüter, M. & Schoon, M. L. *Principles for building resilience: sustaining ecosystem services in social-ecological systems*. (Cambridge University Press, 2015).

Sustainable development outcomes

System-level feedbacks — Emergence + System-level feedbacks
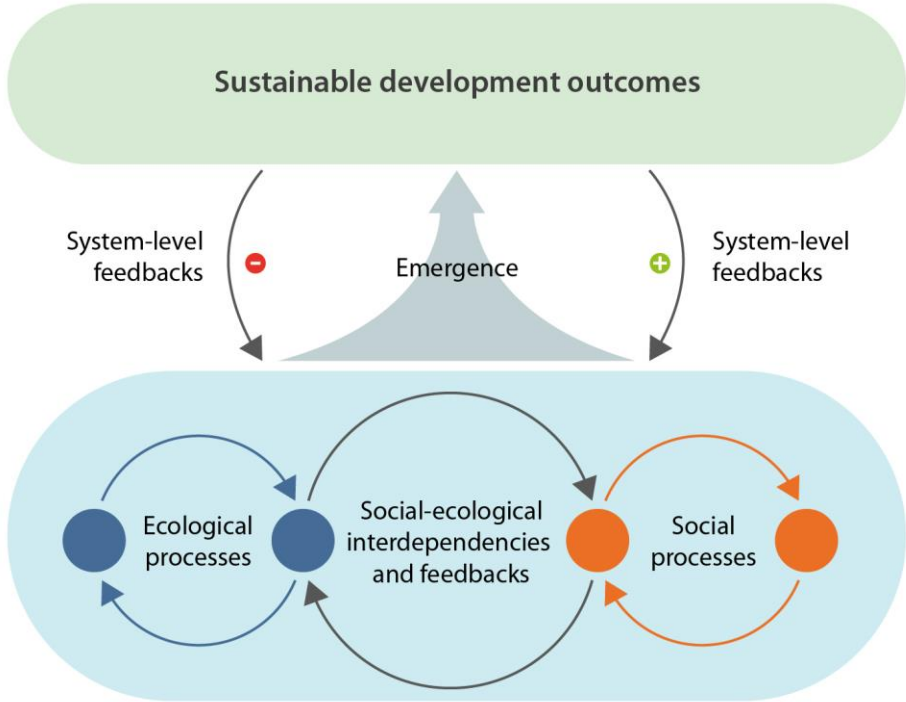
System-level
Focus on processes of emergence and feedbacks

Ecological processes — Social-ecological interdependencies and feedbacks — Social processes

Subsystem-level
Focus on socio-ecological interactions and feedbacks

Goal clusters categorised by nature of feedbacks between SDG targets and biodiversity and ecosystem services	Number of targets:				
	No. of targets in cluster	Assessed	Negative trend	Insufficient progress	Data gaps
Ecological goals	35	27	14 (52)	10 (37)	3 (11)
Social-ecological goals	38	13	7 (54)	4 (31)	2 (15)
Social goals	41	*			
Driver goals	36	*			
Across 16 goals	150	40	21 (53)	14 (35)	5 (13)

*Could not be assessed at target level