ECOLOGY

Integrated index-based assessment reveals long-term conservation progress in implementation of Convention on Biological Diversity

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The Convention on Biological Diversity (CBD) has launched two long-term, target-based conservation Strategic Plans in the past two decades. We compiled an index-based assessment framework to evaluate target achievements of the CBD using long-term indicators. The CBD Index is steadily increasing, with the Goal Indices for biodiversity mainstreaming, protection, and supporting mechanisms all improving over time. While the State and Pressure Indices continue to deteriorate coupled with human population and economic development, their changing rates have slowed down, most likely because of the constantly growing conservation efforts as revealed by the Response Index. The first quantitative assessment of the CBD's long-term performance may provide critical science-based evidence for continuing commitments to developing and implementing a new Post-2020 Global Biodiversity Framework. We also call for enhanced efforts to address the emerging challenges in achieving the 2050 Vision for Biodiversity and the adoption of a rapid assessment framework to track future progress.

INTRODUCTION

In recognition of biodiversity conservation as a common concern of humankind, the Convention on Biological Diversity (CBD), the most important and largest multilateral treaty committing to biodiversity conservation, sustainable use of its components, and the fair and equitable sharing of benefits arising from genetic resources, was launched in 1992 at the United Nations Conference on Environment and Development (*1*). Up to now, the Convention has guided national strategies centered on the above three objectives by initiating national actions in 196 signatory Parties. During this process, two long-term Strategic Plans—Strategic Plan 2002–2010 and Strategic Plan 2011–2020 (including the Aichi Biodiversity Targets)—have been formulated and implemented (*2*, *3*), forming crucial support for the world's commitment to conservation. This ambition to halt biodiversity loss also serves as a foundation to realize the Sustainable Development Goals (*4*, *5*). However, official and scientific reports of two Strategic Plans have announced that most targets have been missed, with biodiversity continuing to decline (*6*–*10*). These reports have presented evidence from various conservation fields and regions, thus establishing a critical knowledge base for the conservation community. However, we argue that the conclusions about conservation drawn from these pieces of information are based either on self-reported national progress of the Parties or on data gathered over inconsistent time scales using different methodologies and sometimes require expert knowledge to reconcile the conflicting results. Therefore, they may convey mixed messages to the public, misinforming them about biodiversity and conservation outcomes. The qualitative judgments on whether a target is achieved may also jeopardize the conservationists' initiative for making further contributions in the long run. Instead, an integrated science-based review (i.e., one built on composite indices) on the long-term progress of the CBD could better disclose the whole picture and assess the effectiveness, contribution, and potential improvement of the CBD. The numerical indices stated in succinct language may readily be interpreted by the media and policy-makers in terms of changing direction and extent, as the Human Development Index (*11*) and the Sustainable Development Goal Index (*12*) have shown. In addition, the indices are also essential for scientists and stakeholders to compare real-time trajectories to anticipated scenarios and identify the turning points in reversing the declining trends (*13*).

To this end, we developed an assessment framework for evaluating the performance of the CBD using indicators that could best reflect the long-term global trends of targets of the two Strategic Plans and proposed an integrated CBD Index to present the overall profile. We also compiled indices for each of the five Strategic Goals and Pressure-State-Benefit-Response (PSBR) categories under the Aichi Targets framework and identified relative progress and shortfalls. Specifically, we compared the conservation achievements to human population and economic growth and found that biodiversity impact has relatively decoupled from social development, which is vital for the delivery of the Sustainable Development Goals (Table 1) (*4*) and Ecological Civilization (*14*). Moreover, this rapid assessment system on target progress is flexible in integrating future targets and indicators under the CBD framework. With the coming of the 15th meeting of Conference of the Parties (COP15), it is a good opportunity to comprehensively review the CBD's achievement using generally accepted indices and incorporate this knowledge to set science-based targets and baselines for the Post-2020 Global Biodiversity Framework (GBF; Table 1) (*15*–*17*).

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Table 1. Glossary of international agreements, organizations, and important indicators mentioned in this research. This table includes brief introductions to the international agreements and intergovernmental organizations mentioned in this paper. It also lists a subset of indicators with acronyms to benefit better comprehension of their meaning.

Term	Description	References
International agreements		
Post-2020 Global Biodiversity Framework (GBF)	The Post-2020 GBF is an upcoming global framework for biodiversity targets for the next decade and beyond, toward the 2050 vision of "Living in Harmony with Nature." It is currently being negotiated under the CBD and will be discussed and adopted at the COP15 in Kunming, China in 2022.	(*17*)
Sustainable Development Goals (SDGs)	The Sustainable Development Goals are 17 goals adopted by the United Nations in 2015 as a blueprint to achieve sustainable development. These goals address global challenges including poverty, inequality, climate change, environmental problems, and so forth.	(*4*)
Global Strategy for Plant Conservation (GSPC)	GSPC was first adopted by the world's governments as a plant conservation program under the CBD in 2002. In 2010, it was updated to include five goals and 16 outcome-oriented targets for plant conservation to be accomplished by 2020, in support of the Strategy Plan 2011–2020 of the CBD. Notable progress at global and national levels has been identified for many targets, with the efforts of the Parties and the botanical community worldwide. These include generating and sharing information on the world's plant diversity (e.g., World Flora Online), establishing networks of important plant areas, and implementing in situ and ex situ conservation programs.	(*24*, *25*)
International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA)	ITPGRFA is an international treaty adopted by the Food and Agriculture Organization (FAO) of the United Nations in 2001. It establishes an international regime on access and benefit sharing of plant genetic resources for food and agriculture, in accordance with the CBD.	www.fao.org/plant-treaty
International organizations		
International Union for Conservation of Nature (IUCN)	IUCN is a union composed of both governmental and nongovernmental organizations established in 1948. It has great influence in assessing the conservation status of species and nature with its publications of the IUCN Red List of Threatened Species, the IUCN Red List of Ecosystems, and the IUCN Green List of Protected and Conserved Areas.	www.iucn.org
Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)	CITES is an international agreement to protect endangered animals and plants, with the aim of "ensuring the international trade in specimens of wild animals and plants does not threaten the survival of the species." It entered into force in 1975 and now includes more than 38,700 listed species with different degrees of protection.	https://cites.org
Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)	IPBES is an independent intergovernmental body established in 2012 to "strengthen the science-policy interface for biodiversity and ecosystem services for the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development."	www.ipbes.net
Global Biodiversity Information Facility (GBIF)	GBIF is an international open data infrastructure dedicated to online biodiversity data sharing, primarily data of species distributions and scientific names. Its goal is to provide open access to these biodiversity data for people worldwide.	www.gbif.org

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Term	Description	References
Marine Stewardship Council (MSC)	MSC is an international nonprofit organization that promotes sustainable fishing across the world. It manages a fishery certification program to assess whether fisheries meet the sustainable fishing standard. It also certifies companies in the supply chains to guarantee that the seafood it certifies is identifiable, segregated, and traceable.	www.msc.org
Concepts used in some indicators		
Ecological Footprint (EF)	EF compares human demand on nature against Earth's available resources. When EF exceeds 1, it indicates that mankind demands more ecological resources and services than the planets could supply to support human likelihoods.	(*61*)
Red List Index (RLI)	RLI can be used to track biodiversity trends over time by calculating the aggregated extinction risk of a given set of species based on their conservation status in the IUCN Red List. Higher RLI values indicate the species group under evaluation has better conservation status and is less threatened, whereas lower RLI values indicate that the species group is at higher risks of extinction. RLI can reflect the state of biodiversity based on representative taxa (e.g., RLI for birds, mammals, amphibians, and corals), and it could also capture specific pressure on biodiversity reflected by related species groups (e.g., RLI for internationally traded species; RLI for forest specialists), as used in this analysis.	(*7*, *67*)
Key Biodiversity Areas (KBAs)	KBAs are sites of global importance for species and their habitats. These sites are identified, monitored, and safeguarded by the KBA Partnership of global conservation organizations.	(*68*)
National Biodiversity Strategies and Action Plans (NBSAPs)	NBSAPs are the main instruments for implementing the CBD at the national level. Aichi Target 17 has emphasized the importance of NBSAPs and asked the Parties to the CBD to "develop, adopt as a policy instrument, and commence implementing an effective, participatory and updated NBSAP" by 2015.	(*3*)

RESULTS

Continuous conservation focuses of two Strategic Plans

In 2002, the COP to the CBD formulated the first long-term Strategic Plan 2002–2010 (*2*) and subsequently designed a framework consisting of 11 principal goals and 21 targets, as well as corresponding indicators to assess their progress (*18*). These conservation targets encompass generally accepted conservation priorities, such as protecting biodiversity components, encouraging the sustainable use of biodiversity, mitigating threats to biodiversity, and preserving ecosystem services. However, none of these targets have been achieved globally, and some are even difficult to assess owing to their vague definition and lack of planning in inherent design (*6*). On the basis of this, in 2010, Parties to the CBD adopted an improved Strategic Plan for Biodiversity 2011–2020 and its associated 20 Aichi Biodiversity Targets, organized under five Strategic Goals (A to E) (*3*), to better address the mounting biodiversity challenges.

To illustrate the continuity, innovativeness, and completion status of the targets for 2010 and Aichi Targets, we examined the targets for 2010 and the Aichi Targets framework, identifying their shared conservation focuses and comparing their periodic fulfillment (Fig. 1). We found that most focal areas of Aichi Targets, such as those in Goal B (direct pressure), Goal C (protection), and Goal D (ecosystem and genetic resources), were inherited from the targets for 2010. These are the long-standing conservation priorities that the CBD has highlighted. In the Aichi Targets, these conservation priorities have been divided into more specific focal points and complemented with emerging issues, as shown by the growing number of elements in the Aichi Targets. Major structure rearrangements lie in Goal A and Goal E, which are proposed on the basis of the reflection that a lack of biodiversity awareness among the public and decision-makers, as well as inadequacy of supportive capacity, is obstructing biodiversity conservation efforts. Therefore, in the Aichi Targets, Goal A is the foundation for the society to reach a consensus on conservation, whereas Goal E calls for multiple sources of support. Although the progress assessments of the 2010 and Aichi Targets are not directly comparable, a comparison of the two could still reveal continuity between fulfilled, unfulfilled, and lagging elements, such as continuous achievements in protected areas (2010 Goal 1 and Aichi Target 11) and insufficiency in conserving ecosystem services and supporting people in most need (2010 Goal 8 and Aichi Target 14).

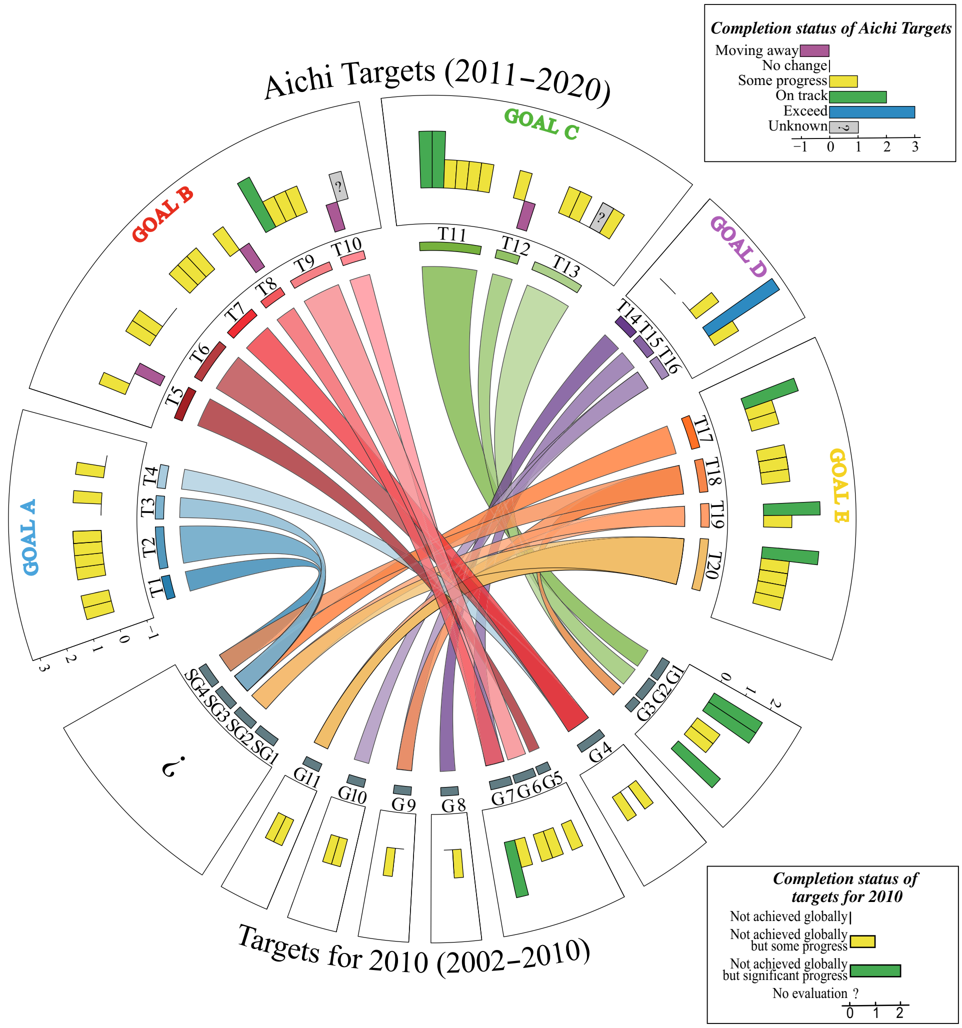

Fig. 1. Linkage and completion status of 2010 and Aichi Targets. This circular plot is composed of the Aichi Targets (20 targets, T1 to T20) and the targets for 2010 (11 goals, G1 to G11, and 4 strategic goals, SG1 to SG4), as indicated by the characters on the middle track. The inner bands link the Aichi Targets and targets for 2010 with shared conservation focus, and the various series of band colors correspond to Goal A to Goal E of the Aichi Targets, respectively. These connections suggest that the Aichi Targets are primarily inherited from the targets for 2010, albeit with structural rearrangement. The bars on the outmost track indicate the completion status of the Aichi Targets and targets for 2010, as assessed by the CBD at the element or subtarget level (*6*, *10*). For the Aichi Targets, a status of 0 denotes no change, 1 (yellow bar) indicates some progress, 2 (green bar) means on track, 3 (blue bar) means exceed, −1 (purple bar) means moving away, and a question mark on a gray bar means unknown. For targets for 2010, a status of 0 implies not achieved globally, 1 (yellow bar) means not achieved globally but some progress, 2 (green bar) means not achieved globally but significant progress, and the question mark for the strategic goals indicates no evaluation.

CBD Indices reveal both long-term progress and shortcomings

To quantify and evaluate the overall achievement of CBD conservation targets, we introduced a CBD Indices Framework that gathered existing up-to-date datasets of global indicators to construct an integrated CBD Index, five Goal Indices for Goal A to Goal E that measure progress toward each goal, and four category indices for Pressure, State, Benefit, and Response (PSBR Indices). The Pressure-State-Benefit-Response framework elucidates the interrelationships between various socioenvironmental aspects, with indicators classified into these categories to monitor pressures driving biodiversity loss, the state of biodiversity components, the benefits derived from biodiversity (such as ecosystem services and genetic resources), and the response from government and society to conserve biodiversity, respectively (*19*). The CBD Indices Framework is in a hierarchical structure where indicators are at the base to develop five Goal Indices and the integrated CBD Index built on them is at the apex; meanwhile, PSBR Indices are paralleled to Goal Indices as they are based on the same dataset and methodology but in a distinct organizational structure, thereby conveying messages from different perspectives (Fig. 2). We adopted the Aichi Targets framework to construct the above indices but used data from 2002 to 2019 (because data for 2020 are barely available) to account for long-term progress for the focal areas. The indicators used in our analysis were selected from the following sources: the indicator list proposed by the CBD for potential use in assessing the Aichi Targets (*20*), global indictors developed by the Biodiversity Indicators Partnership in response to the CBD (*21*), and indicators used in the midterm

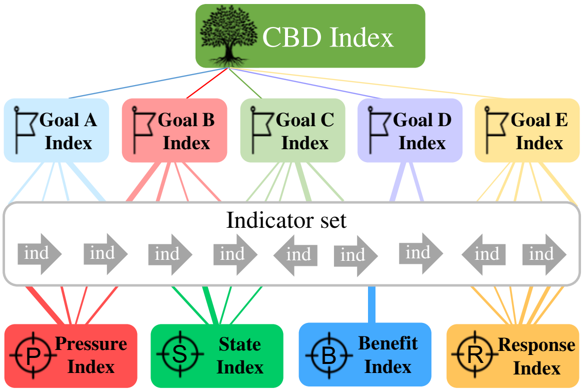

Fig. 2. The hierarchical CBD Indices Framework. The CBD Index is constructed using five equally weighted Goal Indices, and the Goal Indices are calculated using associated indicators with varying indicator numbers and contributions, as demonstrated by the different numbers and sizes of the links from indicator icons to the Goal Indices. Similarly, the PSBR Indices are built using the same set of indicators but in different combinations.

analysis of progress toward the Aichi Targets (*8*). Although more than 100 indicators have been proposed, their data availability varies, most notably in terms of regional and temporal coverage, and their utility in constructing integrated long-term indices is underappreciated. We then screened these indicators according to their representativeness (preferably global data), time series (with at least five data points in both 2002–2010 and 2011–2019), and reliability (with valid measures and open data), which results in a total of 45 highly credible indicators used in the analysis (table S1). Each indicator is associated with a target and falls into one of the four categories: Pressure, State, Benefit, or Response. To determine the importance and contribution of each indicator to the composite Goal indices, we applied the weighted mean method (details in Materials and Methods) to objectively compute each indicator's weight by its relative coefficient of variation (ratio of the SD to the mean). Thus, all available indicators contribute to the Goal Indices construction in linear models, with indicators that fluctuate more drastically receiving higher weights to emphasize the changing circumstances (table S2). We then calculated the CBD Index by averaging five Goal Indices to demonstrate the overall performance of CBD conservation efforts. Similarly, we used indicators in each of the PSBR categories to construct the PSBR Indices (table S3) that monitor mechanistic links of conservation. We also validated the robustness of this index framework in terms of weighting method and number of indicators (figs. S1 and S2). Besides, we examined for significant differences in indicators' annual change rates between the two Strategic Plans' time periods to denote their relative development (Fig. 3C).

Integrated CBD Index

The integrated CBD Index shows an upward trend from 2002 to 2019 with slight fluctuations (Fig. 3A), demonstrating notable progress toward the CBD conservation targets established in the two Strategic Plans. However, given the ongoing loss of biodiversity and the complexity of conservation issues (*22*), larger-scale improvements are still urgently required to maximize the long-term effects of conservation initiatives.

Goal A Index on biodiversity mainstreaming

Goal A from the Aichi Biodiversity Targets framework aims at resolving the underlying causes of biodiversity loss by enhancing public awareness of biodiversity, promoting biodiversity-concerned and biodiversity-friendly government decisions, and transiting to sustainable production and consumption across the society. The aggregated Goal A Index decreases in the first 5 years during 2002–2019 but then reverses and increases for most of the remaining period (Fig. 3B). This implies the development from indifference to biodiversity to raised conservation awareness and better enforcement of environmental policies supported by accumulated efforts. Among indicators associated with this goal, three present significant changes in their annual growth rates between the periods of the two Strategic Plans. These changes reflect a slower decrease in Red List Index (Table 1) for species under impacts of utilization, a faster growth in sustainable fishery supply chains (represented by the number of Marine Stewardship Council Chain of Custody Certification holders in Table 1), and a steadier increase in Ecological Footprint (Table 1), all of which contribute to reducing unsustainable use of biodiversity (Fig. 3C). Besides these quantitative changes, notable progress has been made in improving environmental economics in conservation, with the adoption of the first international standard of environmental economics in the past decade, followed by the incorporation of biodiversity values into national accounting and reporting systems in approximately 100 countries (*23*). The Global Strategy for Plant Conservation under the CBD (Table 1) also incorporated a target to avoid overexploitation of plants caused by international trade, particularly ornamental, medicinal, and aromatic plants, in addition to timbers, through the cooperation with the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Table 1). This has largely promoted the inclusion of plant species in the CITES Appendices, which now number more than 32,800 plant species (*24*, *25*). The development of this conservation goal may be furthered by reinforcing top-down regulations on finance and sustainable industry with the full participation of stakeholders and the public.

Goal B Index on direct drivers

Goal B addresses direct drivers of biodiversity loss, including overexploitation of biological resources and unsustainable production in agriculture, aquaculture, and forestry, as well as other pressures from habitat loss, degradation and fragmentation, pollution, invasive species, and climate change. Synergies between these drivers are posing great threats to biodiversity and need effective management. However, the integrated Goal B Index presents a negative trend throughout the span of the two Strategic Plans (Fig. 3B), suggesting an intensification of direct drivers threatening biodiversity. This finding is consistent with two previous formal reports that found limited progress for related conservation focus (*6*, *10*). If current trends continue, then these drivers may cause irrevocable consequences to accelerate biodiversity loss and ecosystem collapse (*26*, *27*). Despite the failure of most targets under Goal B, we found that several indicators have shown significantly different trends toward impact mitigation between the periods of two Strategic Plans, including those measuring fishery impact on species (Red List Index for species under impacts of fisheries), pollution impact on species (Red List Index for species under impacts of pollution), and invasive species introduction and influence (Red List Index for species under impacts of invasive alien species) (Fig. 3C). Global Forest Resources Assessments have also reported that rates of habitat loss,

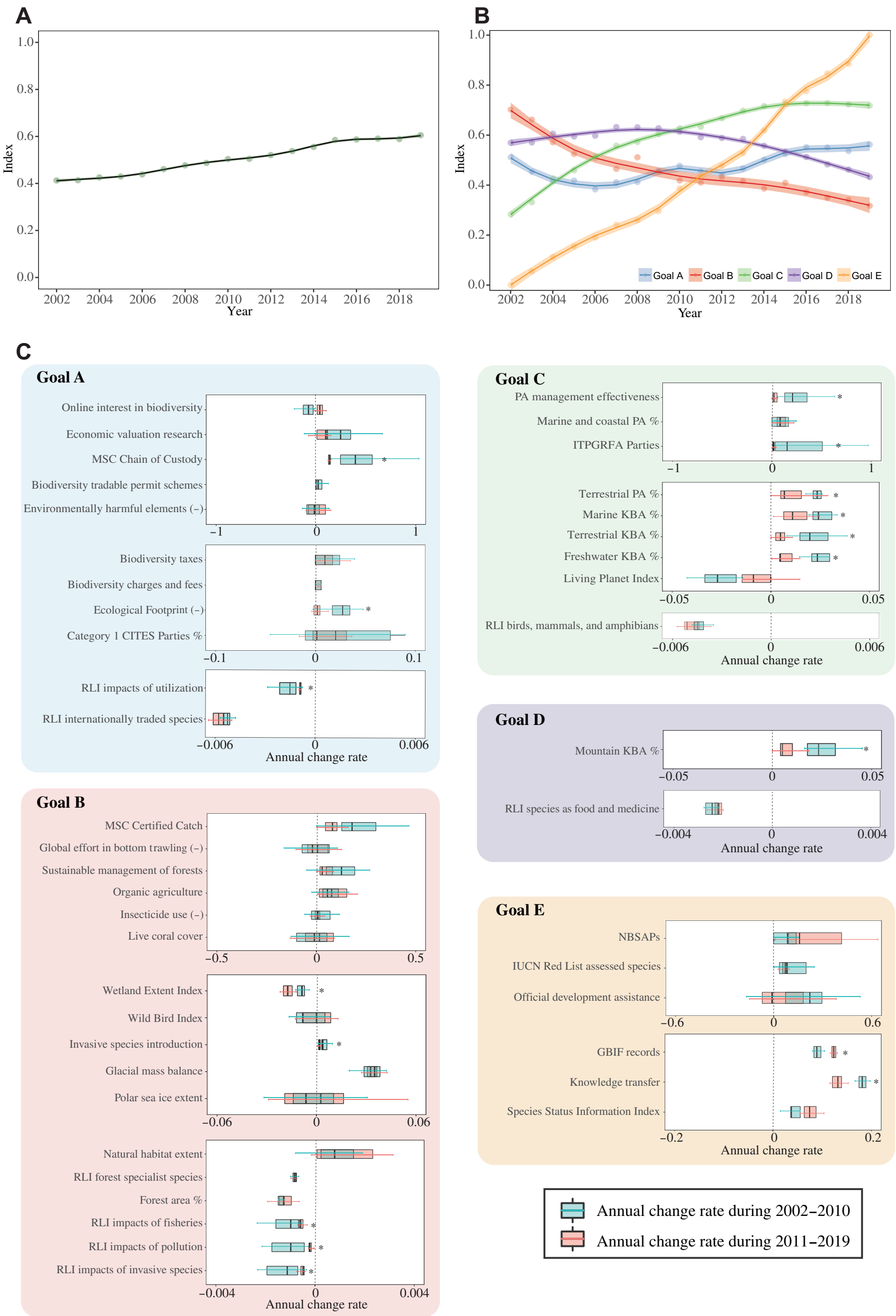

Fig. 3. The CBD Index and five Goal Indices in 2002–2019 with indictors used in building the indices. (**A**) The CBD Index, with a 95% confidence interval, shows a continuous increase during 2002–2019. (**B**) The trajectories of five Goal Indices in 2002–2019, with 95% confidence intervals. (**C**) Box plots of annual change rates for each indicator in 2002–2010 and 2011–2019, where an asterisk indicates significant differences ($P < 0.05$) between the two periods. Most of the indicators are positive (meaning that a higher value indicates a better condition for biodiversity), and a positive value of annual change of these indicators represents improvement year by year, while a negative value of annual change implies that the indicator is decreasing at the certain year. For the four negative indicators (whose value should be reduced to benefit biodiversity) marked by a "(−)" after their name, the contrary is the case. The absolute values of annual change vary depending on the actual values of indicators; therefore, only comparisons between the two stages of the same indicator are meaningful. The full list of indicators along with the shortened forms used in this figure could be found in table S1 (MSC, Marine Stewardship Council; CITES, Convention on International Trade in Endangered Species of Wild Fauna and Flora; RLI, Red List Index; PA, Protected Area; ITPGRFA, International Treaty on Plant Genetic Resources for Food and Agriculture; KBA, Key Biodiversity Area; NBSAPs, National Biodiversity Strategies and Action Plans; IUCN, International Union for Conservation of Nature; and GBIF, Global Biodiversity Information Facility; also see Table 1).

forest loss, including mangrove forest loss, are slowing down but in an unbalanced global pattern (*28*–*30*). However, other indicators show no evidence of reversing the trends, and the loss of wetland is even accelerating. We urge international communities to take necessary measures to alleviate these pressures.

Goal C Index on protection

Goal C of the Aichi Targets aims at conserving the three components of biodiversity, namely, ecosystems, species, and genetic diversity. The integrated Goal C Index demonstrates a detailed developmental process of this conservation area, as it grows consistently since 2002 but levels off in recent years (Fig. 3B). This result indicates a long-term improvement in biodiversity protection, with the exception of a recent standstill influenced by marginal growth in several aspects, including the continued expansion of protected area coverage on terrestrial areas as well as marine, freshwater, and terrestrial Key Biodiversity Areas (Table 1), a further increase of protected area management effectiveness, and the recruitment of members to the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (Table 1 and Fig. 3C). Among the focal areas of this goal, in situ conservation that relies on protected areas has received the greatest attention and effort, though the numerical and qualitative targets have not been completely fulfilled (*31*). Consensus has been reached on the definition and guiding principles of marine protected areas, which have supported a 15-fold enlargement of marine protected areas since the CBD first entered into force in 1993 (*32*). Databases on protected area representativeness, connectedness, and management effectiveness have been developed to guide science-informed actions to fulfill the commitments on protected areas and could potentially enhance index construction when sufficient data are available (*33*–*35*). Emphasis has also been laid on ex situ conservation of species and their genetic diversity, including crop genebank initiatives and conservation programs for threatened and socioeconomically important species, with the participation of the world's zoos, aquariums, botanic gardens, and seed banks (*24*, *25*, *36*, *37*). All of these endeavors contribute synergistically to combating species extinction and loss of genetic diversity. As research has pointed out, situations could be much worse without current conservation measures. For example, 21 to 32 bird and 7 to 16 mammal extinctions have been prevented since the establishment of the CBD, as have 9 to 18 bird and 2 to 7 mammal extinctions within the course of the Aichi Targets (*38*–*40*).

Goal D Index on ecosystem and genetic resources

This goal concentrates on benefits provided by biodiversity, including ecosystem services that our societies depend on, and the benefits derived from genetic resources. The Goal D Index highlights inadequacy in these focus areas since the index grows slowly in the first several years before rapidly declining after 2008 (Fig. 3B). This result is based on a limited number of indicators but is consistent with prior syntheses that reported declines in ecosystem capacity to deliver the essential services (*6*, *10*, *41*). Among the available indicators, one shows a slowdown in the expansion of protected areas covering key mountain biodiversity areas (Fig. 3C). The lack of long-term informative indicators in monitoring ecosystem services, degradation, and restoration implies the lack of knowledge and available data to guide concrete actions, particularly those that address the needs of women, indigenous and local communities, and the poor and vulnerable. Nonetheless, as Aichi Targets 14 and 15 reinforce the importance of ecosystem restoration and resilience, these issues have been made global priorities for research and policies (*42*, *43*), with basic surveys on global ecosystem degradation patterns (*44*) and an ecosystem restoration action plan adopted in 2016 by the Parties to the CBD (*45*) to support future global endeavors. Besides, the Nagoya Protocol, which promotes recognition, behavior, and benefits related to genetic resource sharing, has entered into force under the Aichi Target 16 to accomplish one of the CBD objectives.

Goal E Index on supporting mechanism

Goal E involves strengthening the supporting mechanism for participatory planning, knowledge management, capacity building, and promoting resource mobilization. All indicators with long-term statistics related to this goal have stably improved, forming a continuously growing Goal E Index (Fig. 3B). These conservation activities include the implementation of National Biodiversity Strategies and Action Plans (NBSAPs) (Table 1) in 192 Parties (accounting for 98% of all Parties) by 2020 to build a foundation for sector and cross-sector cooperation, in response to the poor correlations of NBSAPs to national policies before 2010 (*46*); the development of tools, guidelines, and databases related to traditional knowledge (*47*) and the promotion of knowledge sharing and transfer (*48*) including the establishment of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services in 2012 (Table 1) and its series of Global Assessment Report on Biodiversity and Ecosystem Services (*41*); and doubled international financial flows on biodiversity issues and financial assessment, plans, and other mobilizable resources for conservation (*49*). Although indicators for these focus areas are still under development, the proposal and accomplishment of these targets has already represented an enhanced role of the CBD in monitoring and reviewing progress at multiple levels.

Pressure-State-Benefit-Response Indices

Besides the Goal Indices described above, we developed integrated PSBR Indices using the same indicators (table S3) for the feedback-loop Pressure-State-Benefit-Response system. As shown in Fig. 4, the Pressure Index has grown continuously throughout the two Strategic Plans, indicating intensifying pressure on biodiversity. However, segmented regression reveals a decelerating trend after 2004, which reflects the ongoing process of pressure reduction. The State Index shows overall decline with rapid deterioration in 2002–2006 and subsequent deceleration. The Benefit Index also presents a downward trend, but it is built on one single available indicator and should thus be interpreted with caution. These results together indicate that the pressure on biodiversity, the state of it, and the benefits derived from it have deteriorated over the course of the two Strategic Plans, but pressure has been mitigated and state degradation has slowed down during the implementation of the CBD Strategic Plans. Encouragingly, the Response Index, which measures government and societal actions, presents a continuously strengthening trend, with almost all indicators in this category growing constantly. Indices built on the Pressure-State-Benefit-Response system appear to contradict the Goal Indices from the above analyses but also imply that the relatively optimistic situation found in the Goal Indices is mainly due to active responses implemented with short-term effects, rather than genuine improvement of biodiversity. The high proportion of Response indicators (24 of 45) in the indicator dataset may overwhelm the influence of other indicators when constructing the Goal Indices, as more than half of the indicators used in Goal A and Goal C Indices, as well as nearly all the indicators in the Goal E Index, are from the Response category. This is not to say,

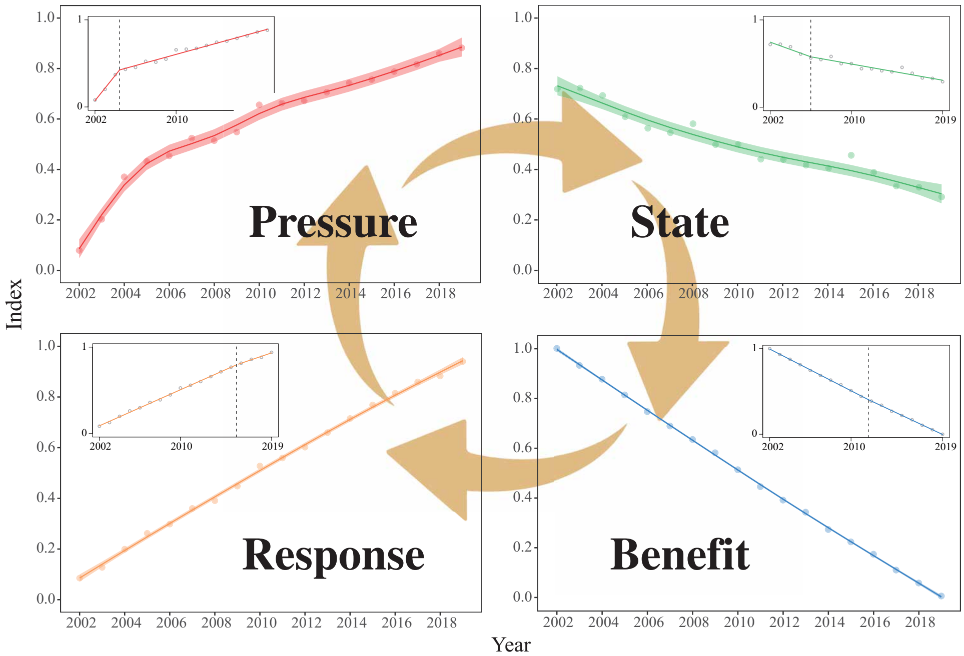

Fig. 4. The PSBR Indices in 2002–2019 and their interrelationships. This figure shows the trends of the PSBR Indices with 95% confidence intervals. Segmented linear regression models are conducted additionally to detect breakpoints (table S4). Here, we reverse the direction of indicators in the Pressure category, thereby a positive trend means growing pressure.

however, that all the attempts to conserve biodiversity are in vain. Instead, these positive actions are an essential prerequisite to make a difference. While the time lag for conservation endeavors translating into outcomes may postpone the visible reversion of the Pressure and State Indices, we have seen indications of pressure reduction and state improvement as shown by their decreasing rates of change. These signs demonstrate the positive impacts of conservation measures, without which the outcomes for the Pressure, State, and Benefit Indices would almost certainly perform far worse.

In addition, biodiversity, ecosystem, and human society are highly intertwined in the socioecological system, where these aspects are synergistic, mutually dependent, and connected through complex feedback mechanisms (*50*). To better understand the conservation progress and outcome, we contextualize the PSBR Indices within the socioecological system and compare them to the metrics of social development. As history has repeatedly shown in different ecosystems and at regional and global scales (*51*–*53*), factors of social development are intrinsically coupled with notable environmental challenges and may act as the fundamental driver of biodiversity crisis (*54*, *55*). The past decades have witnessed the continuous expansion of the human population and economy (*56*). This results in ever-expanding urban areas and enormous material needs, which are considered to cause pressure on the environment and have a detrimental effect on biodiversity state, therefore undermining benefits derived from biodiversity. The overwhelming development at the expense of biodiversity and the ecological environment reflects an unsustainable human-nature relationship, resulting in unbalanced spatial consequences and uncertainties for future generations (*57*). As a result, it is highly improbable that humanity could have withstood impacts on biodiversity and reverse the trends of the Pressure, State, and Benefit Indices during historical development. However, the deteriorating environment would, in turn, undermine the very foundation of human civilization. To reconcile these competing interests, emphasis has been laid on the comanagement of ecological and social systems (*14*, *58*). With the prosperity in many aspects of human society, such as education, health, and the pursuit of spiritual satisfaction, as well as emerging consensus on the interdependencies of nature and man among academia, governments, and the public (*59*, *60*), actions to conserve biodiversity are strongly stimulated, contributing to the rising Response Index. The active responses may then alleviate pressure, restore biodiversity states, and recover the benefits through the linkage between the PSBR framework. These responses also serve as a bond to reconstruct a harmonious socioecological relationship. As the rates of pressure accumulation and state deterioration are brought down (Fig. 4), our analysis presents a shift toward a decoupling of social development and environmental impacts. In other words, the progressive changes in the Pressure and State Indices demonstrate an ongoing tendency toward transforming the interconnection of ecological and social systems to support human development while safeguarding Earth's biodiversity within sustainable thresholds. An example here is the Ecological Footprint, which compares human demand to nature availability (Table 1). As data demonstrate, while the human population and economy continue to grow (*56*), the Ecological Footprint, although still exceeding Earth's carrying capacity, has leveled off since 2010 (*61*), presenting an entry point to rebuild the interconnection between nature conservation and development (Fig. 5). With further economic reform and upscaled conservation activities underpinned by integrative policies and lifestyle changes, we could reach a balancing stage between development and environmental impacts (*62*), which is central to realizing the United Nations' Sustainable Development

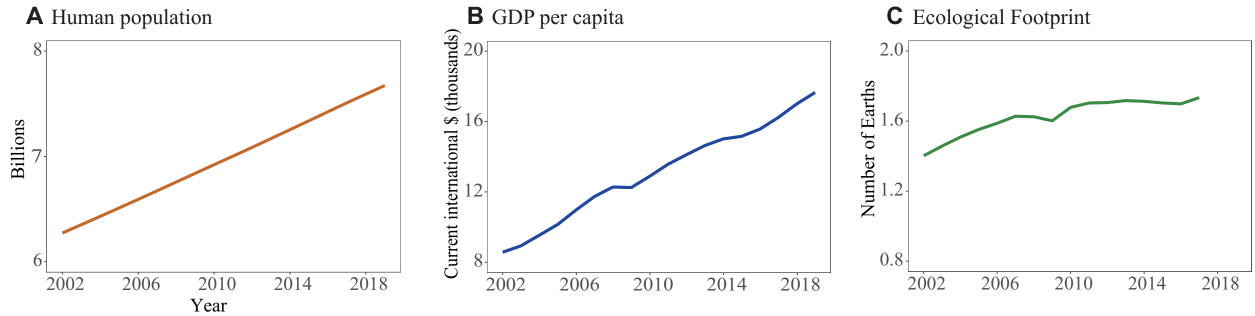

Fig. 5. A comparison of socioeconomic metrics with the Ecological Footprint. Metrics of (**A**) human population, (**B**) economy, and (**C**) Ecological Footprint. Global population size and gross domestic product (GDP) per capita (based on purchasing power parity, current international dollars) have been growing constantly during 2002–2019, except for the financial crisis in 2008, whereas the Ecological Footprint shows marginal growth after 2010. This indicates a decoupling stage of human development and environmental pressure.

Goals as well as Ecological Civilization as suggested by the COP15 meeting (*14*). More powerful responses and system restructuring may trigger the tipping points that thoroughly reverse the trends and transforming the system. However, future design and efforts to adapt these complex dynamics must be founded on a holistic understanding of the long-term development of the CBD, as revealed by our analysis above.

DISCUSSION

The first index-based assessment of the CBD's progress throughout its historical development confirms positive progress toward conservation targets, particularly that policies and measures are starting to bear fruit and mitigate negative impacts. The past decades of joint efforts have laid a solid foundation for biodiversity conservation, upon which we should build future success. As our quantitative analysis is based on an integration of long-term conservation indicators, it also reveals the trajectories for reaching the tipping point and reversing the declining trends in conservation, while also emphasizing the need for addressing lags and underperformance via urgent and scaled-up actions. This should be brought to the attention of international stakeholders and the general public, to motivate them to actively continue the mission.

As the COP15 is taking place, we are also developing this framework in the hope that it would benefit the Post-2020 GBF. The Post-2020 GBF currently under development is built on the theory of change, which recognizes the need for proactive actions to transform the socioecological system to stabilize biodiversity loss over the next decades, recover ecosystems in the following 20 years, and realize the vision of "living in harmony with nature" by 2050 (*17*). Because our quantitative CBD Indices Framework is adaptable to future indicators and data, it may serve as an assessment platform for the CBD, allowing it to track the evolving process toward achieving the vision, identify the transition points in the long-term trajectories, and flag the potential opportunities to adjust pathways toward the 2050 Vision. With the timely progress evaluation and feedback it offers, we will have a clearer picture of where we are, what we have accomplished, and where the gaps remain.

In addition, on the basis of our research, we would like to propose some recommendations for advancing the renewed framework. The target setting of the Post-2020 GBF, apart from being more SMART (*63*), should also be more systematic and consistent across the Strategic Plans so that efforts on those priority areas may accumulate to make substantial differences. We have also found gaps in the coverage and representativeness of existing indicators, which may hinder future progress assessment. As a result, we advocate for enhancing the indicator system with a more balanced number of indicators for each target and Pressure-State-Benefit-Response category to comprehensively capture progress across different aspects. We should be cautious that many of the available indicators were developed to track actions or input to conserve biodiversity, such as the construction of the protected area networks and development of sustainable industries, but not to track the impact of these actions, such as the restoration of species or ecosystem resulted from protection. We strongly advise that future indicators should be developed to monitor nature in parallel with those that measure human responses. Furthermore, long-term, multisource data should be gathered with the Parties' active monitoring and reporting and the commitment of international organizations. Data collection and aggregation at a global scale will lay the foundation and establish a baseline for future assessment. Policymakers should develop more coherent national targets and indicators, taking into consideration whether the national policies will result in actions and how these may boost transformative changes to biodiversity. The future strategies, both global and national, should incorporate more integrated progress assessment approaches and properly account for time lags between responses and changes in pressure, state, and benefits. To meet the long-term conservation vision, our generation bears a vital role in inheriting and pursuing the shared goals to safeguard a legacy that will benefit thousands of descendants.

MATERIALS AND METHODS

Calculating indicator change rates between two periods

We calculated the annual change rates for each indicator between 2002–2010 and 2011–2019 with the following formula

$$\text{Annual change rate}_i = (X_{i+1} - X_i)/X_i$$

where X_i is the value of the indicator in year *i*. We then performed the Shapiro-Wilk test for normality and used a two-sample *t* test to compare the change rates between different periods for normally distributed data, whereas Wilcoxon rank sum test was performed for non-normal data.

Composite index construction

We first defined indicators as positive or negative, with a positive indicator meaning that higher values represent better circumstances for biodiversity and a negative one meaning its value should be reduced to benefit biodiversity. We then standardized the data respectively

For positive indicators

$$X_i' = (X_i - \min\{X_i\})/(\max\{X_i\} - \min\{X_i\})$$

For negative indicators

$$X_i' = (\max\{X_i\} - X_i)/(\max\{X_i\} - \min\{X_i\})$$

We used exponential smoothing forecast to impute missing data (*64*) and then used the coefficient of variation–weighted method to determine the weight of each indicator (*65*). By using this objective weighting method, we eliminate subjectivity in determining the importance of various indicators based on personal knowledge and judgment, instead directly using the information of indicator attributes. Indicators with a relative greater value of coefficient of variation may convey more information and show a greater capacity for distinguishing the changes in achieving the goals, therefore are allocated higher weights, and vice versa. The weights of each indicator and the composite indices are calculated as follows

The coefficient of variation of the indicator j under each goal

$$C_j = \frac{\sqrt{\frac{1}{m}\sum_{i=1}^{m}(X_{ij}' - \bar{X}_j')^2}}{\bar{X}_j'}$$

Weight of the indicator j

$$w_j = \frac{C_j}{\sum_{j=1}^{n} C_j}$$

Integrated Goal Index in year i

$$\text{Goal Index}_i = \sum_{j=1}^{n}(w_j \times X_{ij}')$$

Integrated CBD index in year i

CBD index$_i$ = (Goal A Index$_i$ + Goal B Index$_i$ + Goal C Index$_i$ + Goal D Index$_i$ + Goal E Index$_i$)/5

where n represents the number of indicators within each goal and m denotes the number of years. We also calculated PSBR Indices with identical procedures using indicators from each of these categories. Then, we fitted the indices against corresponding years using the generalized additive model and calculated their 95% confidence intervals. To better illustrate periodical changes in the PSBR Indices, we applied the segmented linear regression model (*66*) to look for a potential breakpoint around 2010 in linear regression models and fitted two linear models with data before and after the year nearest to the breakpoint.

SUPPLEMENTARY MATERIALS

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