Title: A target based on species extinctions for biodiversity policy

Authors: Mark D.A. Rounsevell[1,2,*], Mike Harfoot[3], Paula A. Harrison[4], Tim Newbold[5], Richard D. Gregory[5,6], Georgina M. Mace[5].

Affiliations:

[1]Institute of Meteorology & Climate Research, Atmospheric Environmental Research (IMK-IFU), Kreuzeckbahnstraße 19, Karlsruhe Institute of Technology, Garmisch-Partenkirchen 82467, Germany

[2]School of GeoSciences, University of Edinburgh, Drummond Street, Edinburgh EH8 9XP, UK

[3]UN Environment World Conservation Monitoring Centre (UNEP-WCMC), 219 Huntingdon Road, Cambridge CB3 0DL, UK

[4]UK Centre for Ecology & Hydrology, Library Avenue, Bailrigg, Lancaster, LA1 4AP, UK

[5]Centre for Biodiversity and Environment Research, Department of Genetics, Evolution and Environment, University College London, Gower Street, London WC1E 6BT, UK

[6]RSPB Centre for Conservation Science, the Lodge, Sandy, Bedfordshire SG19 2DL, UK

*Correspondence to: mark.rounsevell@kit.edu

Abstract: The current rate of biodiversity loss breaches both historical precedents and policy commitments. Reversing biodiversity loss will require a simple, policy target that is easy to understand and communicate, and relevant to the vision and goals of the Convention on Biological Diversity. Here, we propose a metric based on global species extinctions, which represents the irreplaceable loss of biodiversity. We propose a long-term goal to return species extinctions to background rates, with a measurable near-term target of keeping described species extinctions to well below 20 per year over the next 100 years across all major groups and ecosystem types. Because extinction is widely understood and extinction targets are simple to communicate, we assert they can galvanize both policy and public support for biodiversity behind a scientifically defensible, policy goal.

One Sentence Summary: Galvanizing the post-2020 biodiversity policy agenda through a single biodiversity target comparable to the 2-degree climate target.

Main Text:

The post-2020 biodiversity policy agenda

Although the continued, worldwide loss of biodiversity arising from human activities is widely known, policy has been unable to arrest the decline (*1*). Of the 20 Aichi biodiversity targets (ABTs) established in 2010 by the Convention on Biodiversity (CBD), only four show good progress while 12 related to the state of nature show significantly worsening trends (*1*). Progress is limited to only a few actions, such as increasing the coverage of protected areas or signing of the Nagoya Protocol (*2*). Much of this failure can be attributed to a lack of mainstreaming of biodiversity in public policy (*2*; pages 741-762), and limitations in raising the profile of biodiversity loss for politicians and the public. With the 2020 target date for the ABTs fast approaching, it is now critical to define a post-2020 agenda that prescribes solutions to arrest the loss of biodiversity. To achieve such an agenda will require a target, underpinned by a clear global goal for biodiversity, which can be readily communicated to galvanize both political will and public support.

While there are many comprehensive proposals that seek to contribute to the post-2020 agenda (3, 4) they focus on achieving conservation actions, such as increasing the coverage of areas dedicated to wildlife, or maintaining intact wilderness, rather than specifying required outcomes for biodiversity (*5*). As such there is a real risk, as with some of the 2020 ABTs, that targets will be met yet biodiversity will continue to decline (*5-7*).

We propose an alternative approach that draws on the theory of change (see Table 1, Table S1 and Table S2). We suggest that the overall impact of a post-2020 biodiversity framework should be the goal of achieving the CBD 2050 vision of "Living in harmony with nature". However, measuring progress towards this goal requires a communicable and actionable indicator and target, which for biodiversity has proven challenging. The climate change community use a single indicator, global mean temperature change, and a target to keep global mean temperature rise below 2°C relative to pre-industrial levels. This indicator and target support climate change mitigation policy under the United Nations Framework Convention on Climate Change (UNFCCC). As a largely political construct, supported by science, the 2°C indicator and target was not intended to represent the multiple dimensions of the climate system and the diverse impacts of climate change. It did provide, however, a rallying point for policy action and subsequent policy agreements, such as the Paris Agreement, in efforts to 'avoid dangerous climate change'. The headline 2°C target has the great advantage of being communicable to a non-science audience and so supports understanding of the ambition in limiting climate change.

Here we outline a proposal for a 2°C-like target for biodiversity (see Table 1). We emphasize that this is not intended to represent all dimensions of biodiversity and we are not proposing a metric that reflects the overall state of nature. This is analogous to global mean temperature, which does not represent most aspects of the climate system. For example, changes in temperature due to climate change are not geographically uniform with temperature changes over land and at high latitudes being considerably higher than temperature changes over the oceans. Temperature is, anyway, only one component of climate. We argue that a comparable simple and measurable indicator is needed to support biodiversity policy with a specific and easily communicated target against which policy responses can be developed and tested. As with the global mean temperature metric for climate change, a single biodiversity metric will inevitably mask considerable spatial variation in the status of biodiversity and will ignore many of the complexities inherent in ecological systems. However, as with climate change, a communicable, 2°C-like target for biodiversity should be supported by a broader range of indicators and targets that more fully describe the state of biodiversity and its drivers of change.

Biodiversity targets based on species extinctions

A single biodiversity metric needs to be both relevant and effective for the goal, as well as being easy to measure and communicate. With this in mind, we propose a metric based on the rate of species extinction. Current species extinction rates clearly exceed those that were characteristic of the past and projected future extinction rates are much higher still, even given large uncertainties (*8*). Over the coming decades, some continuing loss of species is inevitable given the current human domination of Earth's systems, so we suggest an ambitious but achievable rate over the next 100 years (see Figure 1). Thereafter, once there is stabilization of human impacts, we suggest that a rate closer to background rates should be the aspiration (Figure 1).

We propose a measurable, near-term target of keeping described species extinctions to well below 20 per year over the next 100 years across all major groups (fungi, plants, invertebrates and vertebrates) and across all ecosystem types (marine, freshwater and terrestrial). The figure of 20 extinctions per year is based on a target to reduce extinctions to 10 per million-species-years (ten times the upper estimate of natural background extinction rates, and the threshold adopted in the planetary boundaries framework (*9*)) applied to the estimated 2 million species described by science (see Figure 1 and the Supplementary Materials). In proposing this single metric, we are not suggesting that it is sufficient on its own to describe the changing state of biodiversity, or to guide conservation policy, or ecosystem management on the ground. However, we suggest that the extinction rate is a necessary element of any biodiversity policy target, and that it embraces the core concerns that most people have about biodiversity loss. Our justification for basing a global target only on the rate of species extinction is twofold.

First, extinction fully incorporates the most fundamental aspect of biodiversity loss. Each species embodies unique genetic diversity, usually shaped and developed over millions of years of independent evolution. The total body of extant species is the diversity of life on Earth. The extinction of a species represents an irreversible loss, a measurable reduction in the diversity of life on Earth and is the ultimate concern for conservation. While changes in abundance or to ecological communities may be of equivalent concern (*10*), they are in principle, at least, reversible and recoverable. The extinction rate incorporates loss of species and of genetic diversity and therefore two of the core components of the CBD definition of biodiversity.

Second, species extinction is widely understood and easy to communicate. There is widespread public concern about extinctions as was demonstrated recently by the emphasis on the number of species at risk of extinction in the media coverage of the IPBES Global Assessment (*1*). There are collaborative networks recording the world's known and extinct species (www.gbif.org/what-is-gbif and www.catalogueoflife.org) and a program of work to catalogue species close to extinction and to monitor extinctions as they take place (www.iucnredlist.org). We anticipate that targets such as we propose would stimulate new data and novel approaches to monitoring and modelling the status of the world's species.

We fully recognize that measuring only the extinction rate can miss many changes to biodiversity that are of great importance to people, and that underpin the sustainable flow of ecosystem services. It would be possible, in principle, to meet a simple target to reduce the rate of species extinction and yet see wholesale and damaging changes to life on Earth. At the extreme, a single, small population of each species, maintained somewhere (perhaps in a protected area) would result in no extinctions, yet could place ecosystem functioning at risk everywhere, and fail to meet most people's vision for life on Earth. Achieving our target could therefore have some perverse solutions, just as achieving the 2 degrees target can be achieved through perverse actions such solar radiation management, which treat symptoms, but do not address the root problem. Implementation, therefore, requires effective policy scrutiny. Current extinction events can in any case be recorded with the benefit of doubt (see IUCN possibly extinct) to ensure more precautionary reporting.

Policy action, implementation and scaling to the country level

In addition to global extinction rates, additional targets will be needed to ensure that biodiversity meets functional and cultural roles that are especially relevant at local and national scales. This will require countries to develop national targets that are relevant to their own circumstances. For climate change, national targets are defined by Nationally Determined Contributions (NDCs), which outline governmental action towards overall climate mitigation. Likewise, Nationally Determined Contributions for Biodiversity (NDCBs) could provide an action-based context for better protection and management of biological resources and provide governments with a framework within which they could act to achieve global biodiversity targets, including to reduce extinction rates. Governments also need to monitor the effects of NDCBs in real time and use models that project into the future, to evaluate compliance with policy implementation and fine-tune their policy responses.

We are not suggesting that the species extinctions target would be allocated to countries in a top-down policy process. NDCs are voluntary, but monitored through the (independent) Climate Action Tracker to check if countries national targets (which are decided by each country) collectively achieve the global target. One could envisage something similar for biodiversity where country NDCBs for actions within their own country boundaries and actions related to teleconnections are related to both national and global targets. This might lead to a "Biodiversity Action Tracker" or something similar. Then, as with the UNFCCC, an iterative review process would encourage countries to increase their ambition if collectively the global targets were not being achieved.

Generally, countries with the most critically endangered species have the best opportunity to take direct action to mitigate the direct drivers pushing them towards extinction. Hence, national extinction targets need to be clear and sum up to the shared global ambition. Because the proposed global target concerns the number of species becoming extinct within 100 years, it follows that a national target will need to refer to national responsibilities towards reducing the number of global extinctions. National responsibility refers to the geographic location where removal of direct pressures on a species needs to occur, e.g., responsibility for reducing the rate of habitat loss for species in the Atlantic Forest of Brazil would lie in Brazil.

However, in a world increasingly interconnected by trade and the impacts of consumption, the drivers of biodiversity loss often originate, at least in part, in other countries because of consumer demand (*11*). It is important, therefore, for nations to recognize the displacement effects of consumption patterns on biodiversity, along with the moral responsibility to act on this problem. Hence, it is equally important for nations to commit to the direct conservation of species beyond their national borders, since the risk of species extinctions is not equally distributed geographically. A commitment to support biodiversity in other parts of the world would mirror (and complement) efforts to alleviate poverty through international actions that foster development and would tackle the asymmetries inherent in financially poor countries often being biodiversity rich. Thus, the national responsibility for the recovery of species may best be addressed with financial aid, trade agreements, and other means to reduce indirect pressures.

Ways forward

There is a current window of opportunity to put in place an inspiring and credible plan of action for biodiversity recovery in the post-2020 period. The current rate and nature of biodiversity loss is unacceptable because it breaches historical thresholds and policy commitments, and has implications for our economies, livelihoods, food security and quality of life (*1*). A refreshed vision that lays out an achievable ambition to reverse the decline in biodiversity is now urgent. The time is right; there is currently a set of significant pre-conditions to underpin successful policy development and implementation. For example, the policy-relevant information from IPBES assessments, the ambitious goals embodied in the UN SDGs for 2030, and an emerging consensus that links biodiversity recovery to climate change mitigation and adaptation, and to sustainable development and human well-being, as well as the increasing public awareness and demand for action. Together these provide a unique opportunity and one for which the world has all the necessary actors and institutions to exploit.

There is an important role for science in supporting this policy process by advancing understanding of some of the key elements of the theory of change. We need better understanding of the impact of policy actions on biodiversity outcomes and how this supports policy goals, e.g. through a Biodiversity Action Tracker. We need better modelling and futures analyses (target-seeking and ex-ante scenarios) to understand how sets of time-dependent actions encapsulated in alternative development pathways can progress us toward the vision (*2*). We also need scientific advances to investigate what levels of biodiversity loss are damaging for ecosystem functioning, and to fill knowledge gaps about the complex interactions between species extinctions, biodiversity, ecosystem functioning and ecosystem services.

We recognize that a single indicator cannot capture the multiple dimensions of complex systems, and this holds as much for biodiversity assessment as it does for climate change. Ultimately, however, we need to catalyze both policy and public support for biodiversity and its preservation, and to do this we need an indicator and target that readily communicate the urgency of the problem to multiple audiences and enable monitoring of progress. Our proposal for a 2°C-like target for biodiversity based on the rate of global species extinctions attempts to provide a simple, measurable and easily communicated target against which policy responses can be established and tested. Adoption of such a target globally, and its elaboration and implementation nationally, would help integrate the biodiversity and climate change agendas, which is critical for protecting and managing nature sustainably in achieving the Sustainable Development Goals.

References:

1. The Intergovernmental science-policy Platform on Biodiversity and Ecosystem services, *The global assessment report on biodiversity and ecosystem services*, E. S. Brondizio, J. Settele, S. Díaz & H. T. Ngo, Eds. (IPBES Secretariat, Bonn, Germany, 2019).

2. The Intergovernmental science-policy Platform on Biodiversity and Ecosystem services, *The regional assessment report on biodiversity and ecosystem services for Europe and Central Asia*, M. D. A. Rounsevell, M. Fischer, A. Torre-Marin Rando, A. Mader, Eds. (IPBES Secretariat, Bonn, Germany, 2018).

3. E. Dinerstein, C. Vynne, E. Sala, A. R. Joshi, S. Fernando, T. E. Lovejoy, J. Mayorga, D. Olson, G. P. Asner, J. E. M. Baillie, N. D. Burgess, K. Burkart, R. F. Noss, Y. P. Zhang, A. Baccini, T. Birch, N. Hahn, L. N. Joppa, E. Wikramanayake, A Global Deal for Nature: Guiding principles, milestones, and targets. *Sci. Advan.* **5**, eaaw2869 (2019).

4. J. E. Watson, O. Venter, J. Lee, K. R. Jones, J. G. Robinson, H. P. Possingham, J. R. Allan, Protect the last of the wild. *Nature* **563**, 27-30 (2018).

5. P. Visconti, S. H. M. Butchart, T. M. Brooks, P. F. Langhammer, D. Marnewick, S. Vergara, A. Yanosky, J. E. M. Watson, Protected area targets post-2020. *Science* **364**, 239-241 (2019).

6. L. Boitani, R. M. Cowling, H. T. Dublin, G. M. Mace, J. Parrish, H. P. Possingham, K. A. Wilson, Change the IUCN protected area categories to reflect biodiversity outcomes. *PLoS Biol.* **6**(3), e66, (2008).

7. D. P. Tittensor, M. Walpole, S. L. Hill, D. G. Boyce, G. L. Britten, N. D. Burgess, R. Baumung, A mid-term analysis of progress toward international biodiversity targets. *Science* **346**, 241-244 (2014).

8. V. Proença, H. Pereira, "Comparing extinction rates: past, present, and future" in *Encyclopaedia of Biodiversity* (Elsevier, 2017).

9. W. Steffen, K. Richardson, J. Rockström, S. E. Cornell, I. Fetzer, E. M. Bennett, C. Folke, Planetary boundaries: Guiding human development on a changing planet. *Science* **347**, 1259855 (2015).

10. G. M. Mace, M. Barrett, N. D. Burgess, S. E. Cornell, R. Freeman, M. Grooten, A. Purvis, Aiming higher to bend the curve of biodiversity loss. *Nature Sustain.* 1, 448-451 (2018).

11. A. Marques, I. S. Martins, T. Kastner, C. Plutzar, M. C. Theurl, N. Eisenmenger, M. A. J. Huijbregts, R. Wood, K. Stadler, M. Bruckner, J. Canelas, J. P. Hilbers, A. Tukker, K. Erb, H. M. Pereira, Increasing impacts of land use on biodiversity and carbon sequestration driven by population and economic growth. *Nature Ecol. Evol.* **3**, 628-637 (2019).

12. S. L. Pimm, G. J. Russell, J. L. Gittleman, T. M. Brooks, The future of biodiversity. *Science* **269**, 347-350 (1995).

13. A. D. Barnosky, N. Matzke, S. Tomiya, G. O. U. Wogan, B. Swartz, T. B. Quental, C. Marshall, J. L. McGuire, E. L. Lindsey, K. C. Maguire, B. Mersey, E. A. Ferrer, Has the Earth's sixth mass extinction already arrived? *Nature*, **471**, 51–57 (2011).

14. Y. G. Roskov, T. Ower, D. Orrell, N. Nicolson, P. M. Bailly, T. Kirk, R. E. Bourgoin, W. DeWalt, E. Decock, J. van Nieukerken, Zarucchi, L. Penev, Species 2000 & ITIS Catalogue of Life, 2019 Annual Checklist, Species 2000: Naturalis, Leiden, the Netherlands (2019).

15. G. M. Mace, N. J. Collar, K. J. Gaston, C. Hilton-Taylor, H. R. Akcakaya, N. Leader-Williams, E. J. Milner-Gulland, S. N. Stuart, Quantification of Extinction Risk: IUCN's System for Classifying Threatened Species. *Conserv. Biol.* **22**, 1424-1442 (2008).

16. L. N. Joseph, R. F. Maloney, H. P. Possingham, Optimal allocation of resources among threatened species: a project prioritization protocol. *Conserv. Biol.* **23**, 328-38 (2009).

17. P. J. Mayhew, P. J, Why are there so many insect species? Perspectives from fossils and phylogenies. *Biol. Rev.* **82**, 425-454 (2007).

18. M. J. R. Costello, M. May, N. E. Stork, Can we name Earth's species before they go extinct? *Science* **339**, 413-416 (2013).

19. IUCN (2019). The IUCN Red List of Threatened Species. http://www.iucnredlist.org. Cambridge, UK, IUCN.

20. C. Loehle, W. Eschenbach, Historical bird and terrestrial mammal extinction rates and causes. *Div. Dist.* **18**, 84-91 (2012).

21. J. C. Briggs, Species extinction: Frequency and biogeography. *Env. Skept. Critic.* **4**, 96. (2015).

22. V. Clausnitzer, V. J. Kalkman, M. Ram, B. Collen, J. E. Baillie, M. Bedjanič, W. R. Darwall, K.-D. B. Dijkstra, R. Dow, J. Hawking, Odonata enter the biodiversity crisis debate: the first global assessment of an insect group. *Biol. Conserv.* **142**, 1864-1869 (2009).

23. C. Regnier, B. Fontaine, Not Knowing, Not Recording, Not Listing: Numerous Unnoticed Mollusk Extinctions. *Conserv. Biol.* **23**, 1214-1221 (2009).

Acknowledgments:

We would like to thank the following for previous comments on this manuscript: Almut Arneth, Neil Burgess, Stuart Butchart, Andy Purvis and James Watson. MR would also like to acknowledge the financial support of the Helmholtz Association. TN acknowledges funding from the Royal Society. The authors declare no competing interests.

Table 1. The climate change goal, the current CBD 2050 vision and our proposed goal statement, metric, indicator and target for biodiversity, mapped onto the theory of change framework.

	Climate change	**Biodiversity**
Goal	Avoid dangerous climate change: To stabilize greenhouse gas concentrations "*at a level that would prevent dangerous anthropogenic (human induced) interference with the climate system*." It states, "*such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner*."	Avoid damaging loss of biodiversity for people and for nature: the diversity of life on earth is conserved or restored within a timeframe and at a sufficient level to maintain ecosystem functioning and a balanced supply of ecosystem services, for the health and well-being of all people.
Metric	Global mean surface temperature (over time)	Rate of species extinction (number of extinct species per year)

Outcome indicator	Mean global surface temperature change measured relative to pre-industrial	Number of known species declared or presumed extinct in the wild
Target or threshold	Keep global mean surface temperature rise this century to well below 2°C	Keep mean number of described species extinctions to well below 20 per year (see Supplementary Materials for derivation)
Output indicator	GHG emissions	Number of extant, described and assessed species that are classified at the highest risk of extinction, i.e. Critically Endangered
Mitigation actions	Reduce emissions Restore forests ..	See Table S1, but includes areas set aside for wildlife and conservation, species protection and species action plans, trade policies, sustainable land use and agricultural practices

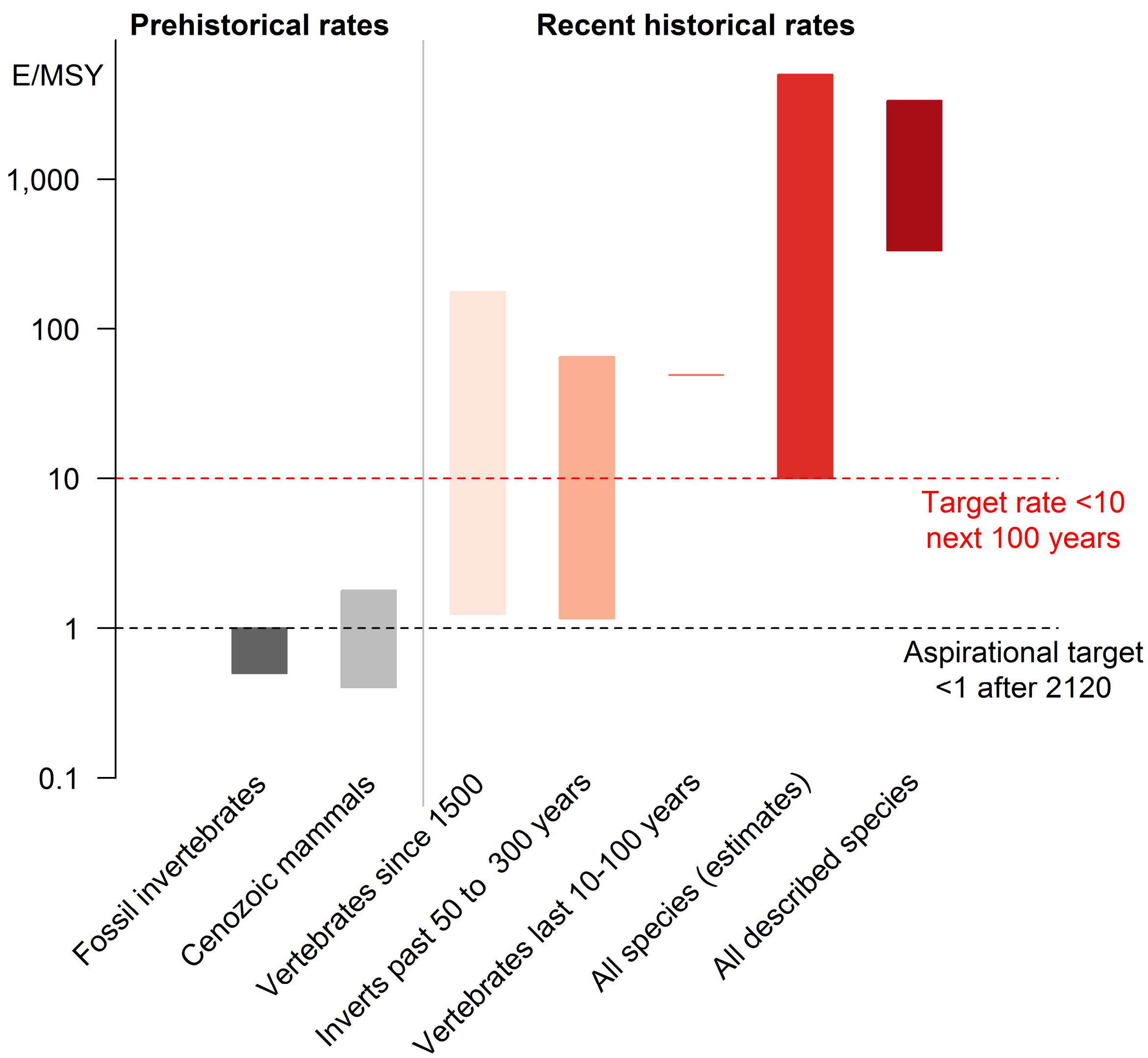

Fig 1. Estimated extinction rates (E/MSY) across a variety of taxonomic groups for different historical time-periods, related to the proposed extinction rate target for the next 100 years and the aspirational target (background extinction rates) from 2120 (see Table S3 for the data sources).

Supplementary Materials for

A target based on species extinctions for biodiversity policy

Mark D.A. Rounsevell, M., Mike Harfoot, Paula A. Harrison, Tim Newbold, Richard D. Gregory, Georgina M. Mace

Correspondence to: mark.rounsevell@kit.edu

Materials and Methods

Framework. We apply the 'theory of change' (Table S1) for achieving progress towards the CBD vision and show how the terminology (Table S2) and framework are comparable with climate change practice (Table 1). The Theory of Change has been used as a critical planning framework in key, high-level policy documents such as the CBD's zero draft framework document released 3 February 2020: www.cbd.int/doc/c/efb0/1f84/a892b98d2982a829962b6371/wg2020-02-03-en.pdf, as well as being used widely by the UN: www.unenvironment.org/about-un-environment/evaluation-office/our-evaluation-approach/theory-change. We show how the theory of change can be used to explore the differences between input and outcome focused targets for biodiversity (see Table S1).

Methods. We translate the CBD vision of 'living in harmony with nature' into an operational goal of preventing damaging loss of biodiversity. A damaging level of biodiversity loss for its own sake has been interpreted as a rate of global extinction that exceeds the background rate. Extinction rates are commonly presented as the number of species extinctions recorded per million-species-years (E/MSY); E/MSY allows comparisons of species extinction rates over different time intervals and considering different numbers of sampled species (*8, 12*). Background extinction rates vary widely, and are substantially elevated during periods of mass extinctions (*13*), but 0.1 to 1.0 E/MSY is characteristic of marine invertebrates in the fossil record (*12*) and 0.4 to 1.8 E/MSY is characteristic for terrestrial mammals (*8*). There is no clear basis on which to determine a detrimental rate of species extinctions, but the planetary boundaries framework suggests that extinction rates should not exceed 10 E/MSY (*9*), i.e. 10 times the background rate. Thus, we propose adopting 10 E/MSY as the target level of biodiversity loss recognizing that achieving the background extinction rates in the fossil record may simply be unrealistic in a human-dominated world. Over the longer term, say after 2100, it should be possible to reduce the target further, say to less than 1 E/MSY due to human activities. This would be possible only if people and nature were to move into a state of equilibrium, genuinely living “in harmony with nature”. Achieving a goal of under 1 E/MSY could also be regarded as having kept the world outside of the sixth mass extinction (*13*).

Converting the rate of 10 E/MSY into numbers of species extinctions requires a time scale and a total species count. For example, 10 E/MSY would be 10 species going extinct out of 10,000 species over a time interval of 100 years. The total number of species is estimated to be close to 9 million, but most of these are not described and the rate needs to be applied to known species in order to be made operational. There are roughly 2 million described species (the Catalogue of Life lists 1,837,565 living and 63,418 extinct species in 2019 (*14*)), so 10 E/MSY would allow no more than 2,000 species to become extinct over a 100-year period, i.e. 20 species per year.

We demonstrate the approach below using the most comprehensive information that is for vertebrates assessed by IUCN (www.iucnredlist.org) recognizing that this is just a subset of the world’s species. Between 1500 and 2019, across all assessed vertebrate species, the rate was 33.6 E/MSY (see Table S3), over three times the allowed rate, although the pace of extinction has been accelerating through time and so recent rates are certainly much higher (*8*) (see Figure S1A).

In order to reduce the number of species going extinct, it is necessary to reduce threat rates among extant species; in general, to reduce the number of species listed as threatened on the IUCN Red List (www.iucnredlist.org). This list includes species at low to high levels of risk, many of which will not go extinct in the next 100 years. In order to predict likely extinctions over the next 100 years (in the absence of new conservation interventions), we use the proportion of species in well-assessed groups that are at the highest risk of extinction (e.g., Critically Endangered on the IUCN Red List) (*15*), excluding those presumed to be already extinct.

To avoid missing the target, the actual number of extinctions over 100 years will require a large reduction in the number of species at the highest levels of extinction risk. This is equivalent to the requirement of reducing greenhouse gas (GHG) emissions in order to meet the 2°C target for climate change. In other words, the use of actual extinctions and very high extinction risk is directly analogous to the use of global mean temperature and GHG emissions for climate change (see Table 1).

Furthermore, intermediate goals could be set for our output indicator, e.g. by setting an interim target for a reduction in the number of critically endangered vertebrate species by 2030, 2040 etc.; this would be analogous to intermediate GHG emissions targets. It is important to note that the target of having fewer than 200 known species becoming extinct by 2120 requires a huge change in the trajectory of extinction risk (see Figure S1). It is debatable, therefore, whether this target can be met whilst the state of biodiversity more widely continues to decline. In other words, meeting the target would require changes that would benefit biodiversity and ecosystems in a broader sense. This is analogous to keeping temperature increases below 2°C, which would ensure that other damaging aspects of climate change (e.g. heatwaves, storms) would be less threatening.

We state the target in terms of recorded extinctions of known, described species. However, it may be necessary, at least at the outset, to implement the target for terrestrial vertebrates only, because this group is sufficiently well assessed that extinctions are likely to be more-or-less comprehensively documented. This means reducing the target total number of extinctions of 2,000 known species (in all groups) per 100 years to 30 terrestrial vertebrate species (see below, and Table S3). Reducing the extinction rate for terrestrial vertebrates over the long term will require the effective conservation of the much larger numbers and diversity of invertebrate and plant species, on which their recovery depends and which their relatively large ranges embrace (*16*). Marine mammals and some plant groups (trees, orchids and cycads) could be included relatively easily alongside terrestrial vertebrates. If, as planned, the coverage of robust assessments in the IUCN list continues to grow, and if countries increase their efforts to comprehensively document and monitor species, then the scope of the target could be broadened to a much wider variety of species more representative of overall biodiversity.

Over time, new groups can be added as the data become available. In addition to IUCN, open-access databases with information that is well curated and regularly updated by networks of experts, such as the Catalogue of Life http://www.catalogueoflife.org/col/info/ac and GBIF https://www.gbif.org/, could be the starting point for necessary data on described species and their estimated extinction dates.

Extinctions (Outcome Indicator). By 2019, 30,873 terrestrial vertebrates (amphibians, reptiles, birds and mammals) had been assessed on the IUCN Red List. A level of 10 E/MSY would have resulted in 156 extinctions from amongst those assessed species since 1500. By comparison, actual extinctions (including species that are Extinct in the Wild) numbered 309 for these groups:

https://nc.iucnredlist.org/redlist/content/attachment_files/2019_1_RL_Stats_Table_3a.pdf.

The counts for extinct species includes species that only persist in zoos and botanic gardens or under very close, supported management. This is the Extinct in the Wild (EW) category in the IUCN Red List that we include with Extinct (EX), as well as those species that are 'Possibly Extinct' according to IUCN. This gives a total number of 'extinct' species of 538. This equates to at least 104 extinctions per 100 years compared to the allowable target of 30. This rate is therefore well over 3 times that allowed at the target rate (and the rate has accelerated in recent decades).

Extinction Risk (Output Indicator). To reduce the future rate of extinction, the number of species with the highest risk of extinction must be reduced. This is our proposed 'output' indicator, analogous to GHG emissions for the 2°C climate target. In 2019, 98,512 species had been evaluated by IUCN of which 2,996 are recorded as being Critically Endangered. This includes, however, many species from groups that have only been partially assessed, and so is potentially biased towards more highly threatened species. Among the 30,873 comprehensively assessed terrestrial vertebrates there are 1,047 species that are Critically Endangered (and not presumed extinct).

Table S1. The theory of change applied to biodiversity with indicative examples*

IMPACT (vision/goal)	From the CBD vision: "*By 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people*"
OUTCOMES (consequences)	• Species extinction rates return to background rates • The abundance and composition of species in ecological communities sustain ecosystem functions • Genetic diversity is maintained • Functional diversity is maintained • Ecosystems contribute to human well-being for all people
OUTPUTS (achievements)	• Extinction risk is reduced across all species groups and across all categories of extinction risk • Protected areas are designated in the right places and effectively managed • Illegal wildlife trade is halted • Unsustainable exploitation of wild populations is halted • Land and waterscapes are managed to support biodiversity conservation and a balanced and equitable supply of ecosystem services • Consumption that degrades biodiversity and ecosystem functioning is not displaced elsewhere • Multifunctional, 'cultural' landscapes are maintained

INPUTS (actions)**	• *Legal and regulatory instruments* established, e.g. protected areas, protected species, species action plans, environmental standards, sustainable land use policies, wildlife trade bans, access rights and responsibilities • *Economic and financial instruments* established, e.g. tax negative environmental impacts, phase out harmful subsidies, conservation financing, reward activities delivering public goods • *Social and information-based instruments* established, e.g. awareness raising, eco-labelling, certification, voluntary agreements, sustainable lifestyles and practices • *Rights-based approaches and customary norms* established, e.g. strengthen the use of Social License to Operate or similar approaches, strengthen the consideration of cultural properties and heritage in protecting sites and landscapes, public participation

*reflecting a hierarchy of targets proposed during the CBD consultation process: https://www.cbd.int/doc/strategic-plan/Post2020/postsbi/birdlife2.pdf

** summarized from IPBES (2018)

Table S2. Definition of terms and analogues from climate policy

Term	**Definition**
Goal	This expresses the desired state of life on Earth and emphasizes the avoidance of risk. In climate change, the goal has been to avoid dangerous climate change.
Metric	It is necessary to devise a metric (or metrics) that quantify progress towards achieving the goal. Given the complex nature of the climate system, and of biodiversity, the metric is necessarily a simplification and an abstraction, but it must clearly relate to the goal. Climate change policy uses mean global temperature.
Indicator	The indicator is an elaboration of the metric, with a temporal and spatial scale, that can be measured, modelled and used to specify a target. In climate science, this is mean global temperature change relative to pre-industrial.
Target	This is the level of the indicator to meet the goal. In climate change policy, this is an increase in the mean global temperature since pre-industrial of 2°C.
Actions	The portfolio of policy and management activities that seek to address specific problems. In climate change policy, this is largely energy policy to cut greenhouse gas emissions and land use policy to reduce greenhouse gas releases to the atmosphere.

Table S3. Summary of datasets that form the basis for estimates of E/MSY (see text). The data need to come from groups of species that have been comprehensively evaluated in some way so that the extinction rate estimates are unaffected by recording bias. The definition of extinction is more precautionary (species are not listed as extinct until there is strong evidence that they no longer persist) and the quality of documentation is generally higher for the IUCN data. However, these data are limited to terrestrial vertebrates, and so may over-represent more threatened groups. We have added data from the Catalogue of Life and from other reviews where the authors have scrutinized whole taxa or assessed a random sub-sample. Here the extinct species are more likely to be under-sampled, especially if they are rare, cryptic, from poorly known groups or went extinct earlier in the time interval. Estimates of E/MSY require a time interval, a known number of species that were examined, and a recorded number extinct. Where there are uncertainties in any of these we provide alternative estimates of E/MSY based on plausible values for any of these metrics. The table indicates where this was done.

Group	**Time period**	**Time interval (years)**	**Number of species in group**	**Number of species extinct**	**E/MSY**	**Source and notes**
Insects	Fossil record				**0.5 to 1.0**	See discussion in (*17*)
Terrestrial mammals	Fossil record				**0.4 to 1.80**	Summary figures for low to high estimates (*8*)
All current species	Contemporary	10 to 100	2m to 8 m	2000 to 40,000	**10 to 5000**	Using range of estimates of timescales and extinction rates (0.1 to 5%) from (*18*).

All described species	Contemporary	10 to 100	1900983	63418	**334 to 3336**	No time period given so range of estimates for E/MSY uses 10 to 100 years. http://www.catalogueoflife.org/annual-checklist/2019/info/ac accessed 02/02/2020 (*19*).
Terrestrial vertebrates (Mammals, birds, reptiles, amphibians)	1500 to 2019	519	30873	538	**33.58**	Number of species is number assessed by IUCN. Extinctions include Extinct (EX), Extinct in the Wild (EW) and Possibly Extinct (CR(PE)). (*19*). Most rigorous estimate.
Terrestrial vertebrates (Mammals, birds, reptiles, amphibians)	1501 to 2019	519	30873	309	**19.28**	Number of species is number assessed by IUCN. Extinctions include Extinct (EX) and Extinct in the Wild (EW) only (*19*). Most rigorous estimate
Terrestrial mammals on islands	1500 to 2000	500	783	58	**148**	(*20*)
Terrestrial mammals on continents	1500 to 2000	500	3704	3	**1.62**	(*20*)
Birds on islands	1500 to 2000	500	1377	122	**177**	(*20*)
Birds on continents	1500 to 2000	500	9677	6	**1.24**	(*20*)
Terrestrial vertebrates from IUCN		100	26766	132	**49**	Past 100 years only. From (*8*) using (*19*) data. Most rigorous estimate.

Butterflies (Lepidoptera)		50	17280	0-3	**0-3.47**	Assuming that they were fully assessed. Timescale not given but from text deduce it is shorter that centuries (*21*). Could be under-estimate.
Dragonflies and damselflies (Odonata)		50	5680	0-2	**7.04 to 35**	From (*21*). Timescale not given but from text deduce it is shorter that centuries (*21*). (*22*) found no extinct species in a random sample of 1500 species. Could be under-estimate.
Mollusca		100	87000 to 200000	566	**28-65**	Assuming that they were fully assessed. Timescale not given but from the text we deduce it is shorter than centuries. Most extinct species are island endemics with very low extinction rate among continental species (*23*)
Aspiration for all species	**After 2120**	**100**	**2000000**	**200**	**1.00**	**Aspiration 2 extinctions per year to get to background rate**
TARGET for all species	**2020 to 2120**	**100**	**2000000**	**2000**	**10**	**Target to 2120 - 20 extinctions per year**

Figure S1. The extinctions target in context based on vertebrates, the only group for which our proposed extinction rate can currently be estimated. For the vertebrates, the allowable extinction rate over 100 years would be 30 (see SI for detailed explanation), This is substantially lower than vertebrate extinctions in the recent past (A), which have been increasing in frequency and the recent slowing is probably a reporting lag only. The future trajectory of these extinctions is likely to begin with a steep increase continuing because of species that are committed to extinction arising from historical pressures and lagged responses (B). For the number of extinctions to stabilize, action will need to be taken to improve the conservation status of species that are currently at very high risk of extinction. So, the number of critically endangered species should begin to slowly decline and then potentially accelerate downwards as actions take effect (C). For these trajectories to unfold, actions (inputs) must increase immediately and dramatically relative to the present (D). It is likely that actions will need to remain high for several decades, and subsequently ease off as biodiversity stabilizes in a sustainable world. Alternatively, actions may need to increase if the effects of long-lived pressures, such as land use or climate change, continue to grow.