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Supplementary Materials for

A target based on species extinctions for biodiversity policy

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Materials and Methods

Framework. We apply the 'theory of change' (Table S~~1~~2) for achieving progress towards the CBD vision and show how the terminology (Table S3~~2~~) and framework are comparable with climate change practice (Table S1). 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 S~~1~~2).

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 S~~3~~4), 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 S1).

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 S~~3~~4). 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).

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Table S1. 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 S2, but includes areas set aside for wildlife and conservation, species protection and species action plans, trade policies, sustainable land use and agricultural practices

Table S~~1~~2. 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 S~~2~~3. 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 S~~3~~4. 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**

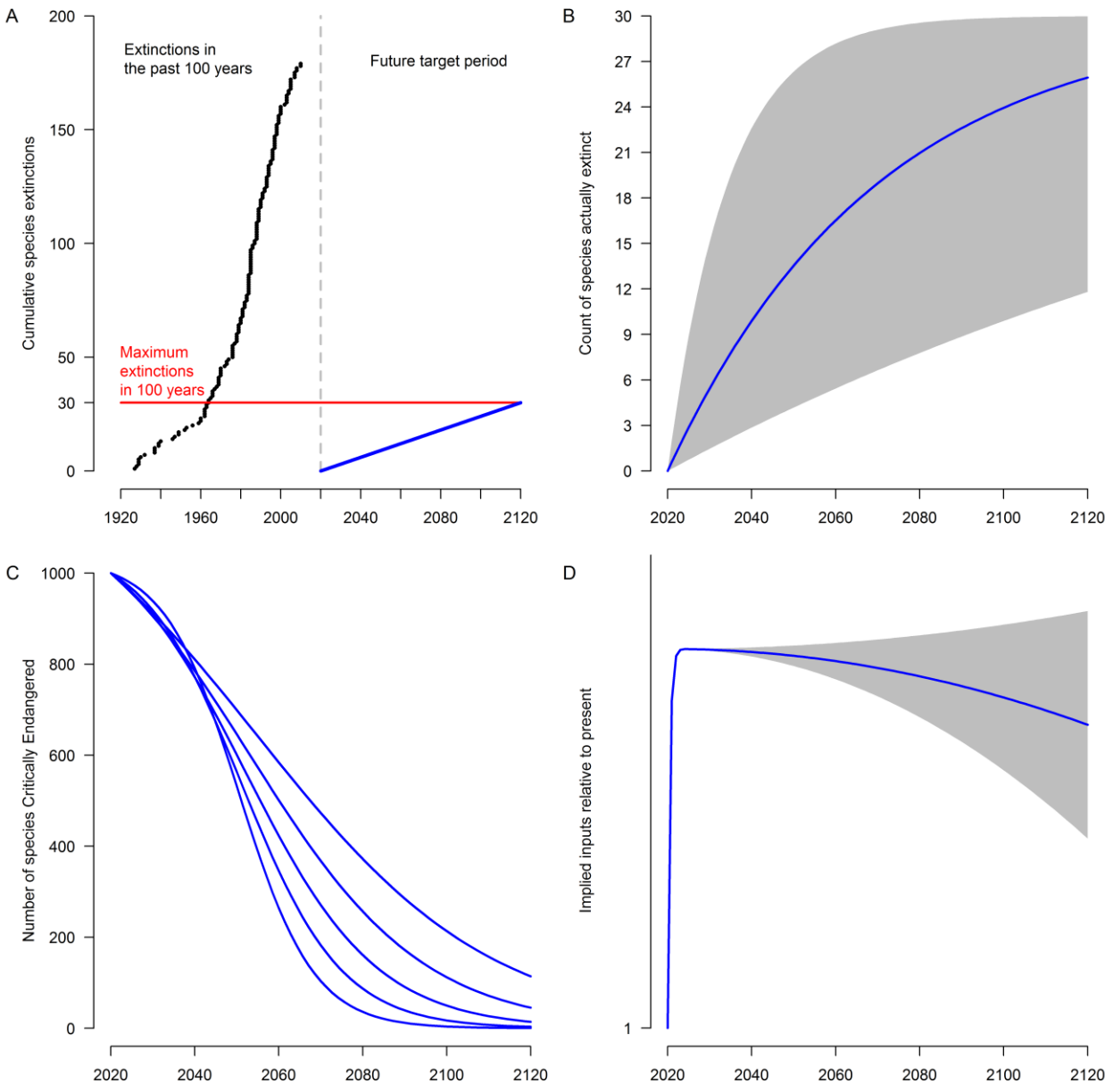

Figure S1. The extinctions target in context based on vertebrates, the only group for which our proposed extinction rate can currently be estimated. For the vertebrates, the allowable extinction rate over 100 years would be 30 (see SI for detailed explanation), This is substantially lower than vertebrate 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.