A climate-biodiversity funnel that accelerates action towards global goals

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Abstract: Joint action on climate and biodiversity is urgently needed to meet the goals of the Paris Agreement (PA) and Kunming-Montreal Global Biodiversity Framework (KM-GBF). Here, we analyse interlinkages between targets in these two landmark international agreements. We find recognition of climate-biodiversity interactions in the agreement texts (three KM-GBF Targets and four PA Articles), demonstrating scope for formally integrated action. Quantitative analysis indicates that climate-biodiversity interactions generate a 'funnel' (bounded by 0.54 (0.32-0.80) $GtCO_2$/Mha) towards achieving PA Article 2 and KM-GBF Target 2. Within the funnel there is a 'channel' in which synergies are maximised. The funnel highlights the complex dynamics that can emerge from the interplay of climate and biodiversity and provides a simple filter to prioritize effective joint action.

Introduction

The nexus of climate and biodiversity will be in the spotlight this November at the 30th Conference of the Parties (COP30) to the United Nations Framework Convention on Climate Change (UNFCCC) in Belém, Brazil. The COP is expected to serve as a platform for showcasing and coalition-building for ecosystem-based adaptation, an approach that involves biodiversity and livelihood considerations in planning adaptation to climate change[1]. The meeting comes at a time of climate crisis where global warming has nearly passed 1.5°C, climate impacts are escalating and some climate and biosphere tipping points may already have been passed.

Interest in climate-biodiversity interactions has been galvanized by a comprehensive 'nexus assessment' from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)[2] and by joint IPBES and Intergovernmental Panel on Climate Change (IPCC) workshops[3]. These reports present extensive evidence of interactions within the nexus of biodiversity, water, food, health and climate change, while identifying critical gaps in integrated governance and financing. A key message is the need for cross-sectoral collaboration and policy coherence to address these interconnected challenges effectively. The findings underscore the urgency of aligning climate and biodiversity goals to avoid unintended trade-offs and maximize co-benefits.

Here, we first examine to what extent interactions on climate and biodiversity are expressed in their landmark international agreements and therefore provide a basis for formal governance of these interactions. For climate, the Paris Agreement (PA) is a legally binding, international treaty under the UNFCCC, signed in 2016, to limit climate change to well below 2°C and pursue efforts to limit climate change to 1.5°C. Further research has demonstrated that dangerous anthropogenic climate change, prevention of which is the primary objective of the UNFCCC, will occur beyond 1.5°C[4,5]. For biodiversity, the Kunming-Montreal Global Biodiversity Framework (KM-GBF) was adopted in 2022 by parties to the United Nations Convention on Biological Diversity (UNCBD). The Framework sets out a shared vision of a world living in harmony with nature and provides goals to be achieved by 2050 and targets by 2030 progressing towards this vision.

Second, we highlight the importance of the relationship between climate and biodiversity in achieving these goals by analyzing a specific feedback loop between the PA's Article 2 and the KM-GBF's Target 2. These goals call for limiting warming to well below 2°C and for at least 30% of degraded ecosystems to be under effective restoration by 2030, respectively. They provide quantitative targets directly linked to states of climate and nature. Our results suggest a guideline or heuristic for synergistic policy pathways within which climate-biodiversity interactions funnel progress towards global climate and biodiversity goals.

Such integrative heuristics are frequently used in research and policy. For example, the "exponential roadmap" of halving emissions each decade offers a scientifically grounded, easily understood guide to decarbonisation rates[6]. Research into the planetary boundaries, which summarize complex Earth system processes into scientifically-based guardrails for nine boundaries, is the most cited non-economics research in policy documents worldwide[7]. Similarly, the safe and just Earth system boundaries summarize complex Earth system and justice considerations into a set of operational boundaries to guide science-based targets for cities and businesses[8]. The PA and KM-GBF themselves summarize complex climate and biodiversity processes into a limited set of targets. While such heuristics necessarily integrate over many important details, these simplifications are offset by their power to communicate science.

Methods

Interactions expressed in agreement texts

We analyse the KM-GBF and PA texts for acknowledgements of interlinkages between climate and biodiversity (Table S1). In the KM-GBF, which is longer than the PA, we limit our analysis to the Introduction and the 2030 Targets, which are the most operational of the different types of goals in the KM-GBF. Our analysis distinguishes between:

- Interactions involving state variables or pressure variables. In this context, state variables are the level of warming or area of degraded ecosystems and pressure variables are human activities that generate emissions or change land cover. For example, co-benefits are counted as (beneficial) interactions associated with pressures on climate or biodiversity, while forest carbon sinks are state interactions.
- Explicit and implicit references to climate or biodiversity. For example, "biodiversity", "forests", "climate", "carbon" are explicit references, while "sinks of greenhouse gases" are counted as implicit references.
- The direction of a causal relationship expressed by the text. For example, a reference to climate in the KM-GBF may acknowledge the impact of climate on biodiversity or of biodiversity on climate.

Quantitative assessment of interaction strengths

To illustrate the importance of climate-biodiversity interactions, we examine a specific nexus of interactions involving the temperature targets of PA Article 2 and the ecosystem area restoration target of KM-GBF Target 2. Our analysis incorporates the feedback in which climate change undermines ecosystems (recognized in KM-GBF Target 8) and ecosystem loss accelerates climate change (recognized in KM-GBF Target 11 and PA Article 5). To extract assessments of the strengths of these two interactions from the scientific literature, we first examined two recent high-profile reviews of climate-biodiversity linkages, the IPCC-IPBES Working Group report[9] and the IPBES Nexus Assessment Summary for Policymakers[2], the relevant references. We found additional references by snowballing from those references plus the recently published Fesenmyer et al.[10]. We prioritise recently published works.

First, we estimate the extent to which ecosystem restoration will mitigate climate change. We find eight appropriate references (Table S2). Many of the references do not find sufficient restoration area to meet KM-GBF Target 2, for example due to excluding cropland; calculating the coefficient above therefore amounts to extrapolating their estimates to the 30% target. Using the results reported in these references, we divide the additional carbon sequestered by the ecosystem area restored to obtain an interaction strength. Where needed, we use a Transient Climate Response to Emissions (TCRE) of 1.65°C per 1000 PgC[11] (4.5×10^{-4} °C/$GtCO_2$) to convert the interaction strengths between units of °C/Mha and $GtCO_2$/Mha.

Estimates of potential restoration area and associated carbon sequestration vary widely due to differing assumptions, including whether: croplands are assessed as eligible for restoration; only reforestation or restoration of other ecosystem types are included; albedo effects are considered; socioeconomic constraints and trade-offs are addressed; and disturbance regimes (e.g. fires) and other feasibility constraints are accounted for. We represent these variations with uncertainty ranges for our interaction estimates. Our analysis also simplifies interactions by averaging them globally, excluding non-linear dynamics and time-lags and only considering terrestrial ecosystems.

We apply the same interaction strength both to climate mitigation from ecosystem restoration and to climate change from ecosystem loss. That one of the eight references[12] assesses the latter and we find it gives an interaction strength (0.33 $GtCO_2$/Mha) well within the range of all estimates (0.10-0.54 $GtCO_2$/Mha) builds confidence in this assumption.

Second, we estimated the extent to which climate change degrades ecosystems. We found only two relevant references with metrics involving plants and ecosystem or habitat area, as a good indicator of degraded ecosystem area (Table S3). Both references used multiple RCP scenarios over the period 2015-2050. We extracted the change in area for each scenario (Table S3, 'raw data'). The references expressed the change as a percentage relative to current ecosystem area, which we multiply by the current undegraded ecosystem area to obtain an area degraded in Mha.

To estimate the current undegraded ecosystem area, we subtracted a current degraded area of 2870 Mha[13] (noting there are a wide variety of estimates in the literature) from a total ice-free land area of 13,000 Mha, leaving 13,000 - 2870 = 10,130 Mha. The restoration prescribed by KM-GBF Target 2 is therefore equivalent to an area of 2870 × 30% = 861 Mha.

We then divided these scaled area estimates (Table S3, 'scaled data') by the warming associated for each scenario. In the absence of transparent data on the climate model output associated with each analysis, we used the RCP database (https://tntcat.iiasa.ac.at/RcpDb) to estimate changes in CO_2-equivalent concentrations between 2015 and 2050 of 406.795 to 455.441, 401.689 to 505.132 and 410.575 to 628.43 ppm for RCP 2.6, 6.0 and 8.5, respectively. Using a Transient Climate Response to doubling of atmospheric CO_2 (TCR) of 1.7°C[14], we inferred temperature rises over this period of 0.29, 0.60 and 1.11°C for the four scenarios, respectively, using the formula TCR × log(concentration change)/log(2).

Similarly to the first interaction, we use the same strength for both ecosystem area lost from increasing climate change and ecosystem area gained from reducing climate change. This assumption holds because large-scale reductions in atmospheric greenhouse gas concentrations are unlikely: our analysis instead shows the marginal effect of climate mitigation interventions compared to a likely background of stable or increasing atmospheric greenhouse gas concentration.

Mathematical analysis

Let C be the level of climate change (change in global mean surface temperature since pre-industrial, °C), E be an amount of warming arising from emissions, B be the change in area of degraded lands since 2020 (Mha; positive number denotes less degraded land) and R be an area of degraded lands restored by people. Regarding interactions, let a be the reduction in warming per degraded land area restored (°C/Mha) and b be the increase in area of degraded land per unit climate change (Mha/°C). An approximate estimate of the effects of interactions on climate and land restoration actions is therefore (Supplementary Methods).

$$\begin{bmatrix} B \\ C \end{bmatrix} = \frac{1}{1-ab} \begin{bmatrix} 1 & -b \\ -a & 1 \end{bmatrix} \begin{bmatrix} R \\ E \end{bmatrix}.$$

We use this equation to estimate the effects of the above interactions on three large-scale policies related to ecosystem restoration and climate mitigation (Table S4): round 2 Nationally Determined Contributions (NDCs) submitted under the Paris Agreement; widespread bioenergy carbon capture and storage (BECCS); and a widespread transition to low-meat diets. We also use this equation to calculate other characteristics of the 'funneling' effect of the interactions (Supplementary Methods).

This analysis illustrates global patterns and does not resolve the local, ecosystem-specific differences that influence the effectiveness and sequestration potential of restoration actions. Nevertheless, this type of analysis permits estimates of the climate-biodiversity feedbacks that would be challenging to implement in spatially-explicit, uncoupled models and does so using studies that have included many of these local constraints.

Results

Agreement texts recognize interactions

We found that three KM-GBF targets (8, 11, 19), four PA articles (4, 5, 7, 13) and the agreements' introductory matter mention climate and biodiversity, respectively (Table S1, Fig 1). In the KM-GBF, Target 8 aims to minimize climate change impacts on biodiversity, Target 11 includes restoring nature's contribution to climate regulation and Target 19 seeks to align financing for climate and biodiversity goals. In the PA, only the preamble names biodiversity. Articles 5 and 7 refer to sustainable management of carbon stocks in forests and that climate adaptation should include building the resilience of ecological systems, both of which we count as explicit references to biodiversity-related concepts. Articles 4 and 13 refer to the importance of "sinks of greenhouse gases" for climate mitigation and reporting, respectively, which we interpret as implicit references to biodiversity. While these cross-references between climate and biodiversity are limited—appearing in 14% of PA Articles and 13% of KM-GBF Targets—they nonetheless establish a formal basis for integrating climate and biodiversity governance.

Both agreements express climate-biodiversity interactions in terms of state and pressure variables (Fig. 1), yet a pattern emerges in how these relationships are framed. Interactions where a change in climate causes a change in biodiversity are most often expressed as interactions between pressure variables: for example, cobenefits of climate mitigation actions for ecosystem restoration. Interactions where a change in biodiversity causes a change in climate, meanwhile, are most often expressed in terms of states of climate and biodiversity: for example, the role of intact forests in storing carbon. Exceptions to this pattern include KM-GBF Target 8, which calls for minimizing the impacts of climate change impacts on the state of biodiversity, and Target 19, which calls for optimising the mutual co-benefits between climate and biodiversity finance. We therefore find that while KM-GBF Target 8 acknowledges climate impacts on biodiversity, such interactions are underrepresented across both agreements more broadly.

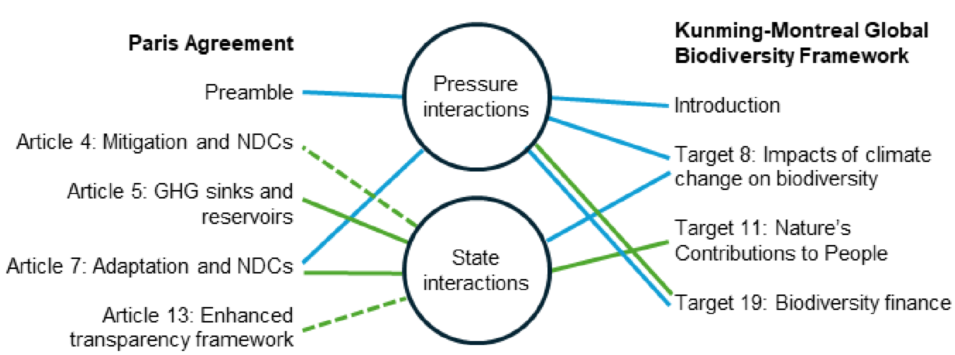

Figure 1: References to climate and biodiversity in the KM-GBF and PA, respectively. We distinguish whether the reference is explicit (solid line) or implicit (dashed line), whether the reference is expressed as a pressure (top circle) or state (bottom circle) interaction and whether the reference involves biodiversity change causally affecting climate change (green line) or vice versa (blue line). Evidence for these links is provided in Table S1. Names of the KM-GBF Targets have been shortened and descriptive names for the PA Articles have been added.

A climate-biodiversity funnel

Synthesizing recent literature (see section Methods), we estimate that ecosystem restoration sequesters a globally-averaged 0.28 (0.10-0.54) $GtCO_2$/Mha and emissions lead to degradation of 0.95 (0.84-1.06) Mha/$GtCO_2$e. Using these interaction strengths, we estimate the cumulative effects of this climate-biodiversity feedback on ecosystem restoration and climate mitigation actions (Supplementary Methods).

This analysis reveals a 'climate-biodiversity funnel' in which certain policy and action combinations are reinforced by positive feedbacks and accelerate progress toward PA Article 2 and KM-GBF Target 2, starting from the current state of climate and ecosystem restoration (Fig 2). For example, transforming food systems in line with the EAT-Lancet planetary health diet[15], which reduces emissions and frees land for restoration, falls within the funnel and would trigger a virtuous cycle towards the global goals. Outside the funnel, interactions divert trajectories away from these goals. The second round of Nationally Determined Contributions (NDCs) submitted through the PA, which would limit warming to 2.6°C and achieve a small degree of restoration, would be swept far away from the global goals by this same feedback in which the loss of biodiversity negatively affects the efforts towards limiting climate change. Widespread bioenergy carbon capture and storage (BECCS) in the scenario considered here (Table S4) lies on the edge of the funnel; interactions therefore counteract both its climate mitigation and ecosystem loss in roughly equal proportion.

We use the term 'funnel' in the sense of channeling action in a particular direction. In our case, synergistic policy pathways that enhance feedback between climate and biodiversity are funneled toward joint achievement of PA Article 2 and KM-GBF Target 2. Visually, imagine a side-on view of a literal funnel that directs a large mass of water or other liquid together and downwards towards some target. In our case, action within the funnel space leads to mutually reinforcing dynamics and greater policy efficacy. In contrast, action outside the funnel can amplify trade-offs and feedbacks that undermine progress toward both goals. Metaphorically, our use of the term aligns with terms such as 'sales funnel' or 'learning funnel' that gathers action towards some desirable endpoint. Mathematically, our funnel is formally described as a saddle that is characterised by two axes: one axis (the 'funnel edge', Fig 2) that returns potential actions towards the current state of climate and biodiversity; and one axis (the channel at the 'funnel bottom', Fig 2) that accelerates actions away from the current state. While the metaphor is simplified, it effectively captures how policy choices can either accelerate or derail synergistic outcomes.

We estimate that the funnel's edge is at an emissions threshold of 0.54 (0.32-0.80) $GtCO_2$ per Mha ecosystems restored (see section Methods). This threshold offers a simple heuristic for prioritising climate and biodiversity actions. At this edge, emissions and restoration actions counteract each other in approximately equal measure. Actions not exactly on the funnel edge will generally be accelerated away from the edge. For example, beneficial feedback arises from actions in which no more than 0.54 $GtCO_2$ is emitted at the same time as 1 Mha of ecosystems is restored, such as through fuel emissions associated with restoration activities. Detrimental feedbacks will push actions where more than 0.54 $GtCO_2$ is emitted per 1 Mha ecosystems restored further away from PA Target 2 and KM-GBF Target 2.

The channel at the 'bottom' of the climate-biodiversity funnel describes the actions that benefit from the strongest synergies towards the goals. Our analysis suggests that actions with 0.54 $GtCO_2$ sequestered per 1 Mha ecosystem restored will be accelerated by over 50% due to the reinforcing feedback generated by the climate-biodiversity interactions we considered (see section Methods). The 0.54 $GtCO_2$ per Mha carbon sequestration to reach the channel at the bottom of the funnel is additional to the 0.28 $GtCO_2$/Mha accounted for in our analysis via state interactions; any action that involves ecosystem restoration would therefore need to reach a total sequestration of approximately 0.9 $GtCO_2$/Mha to reach this channel.

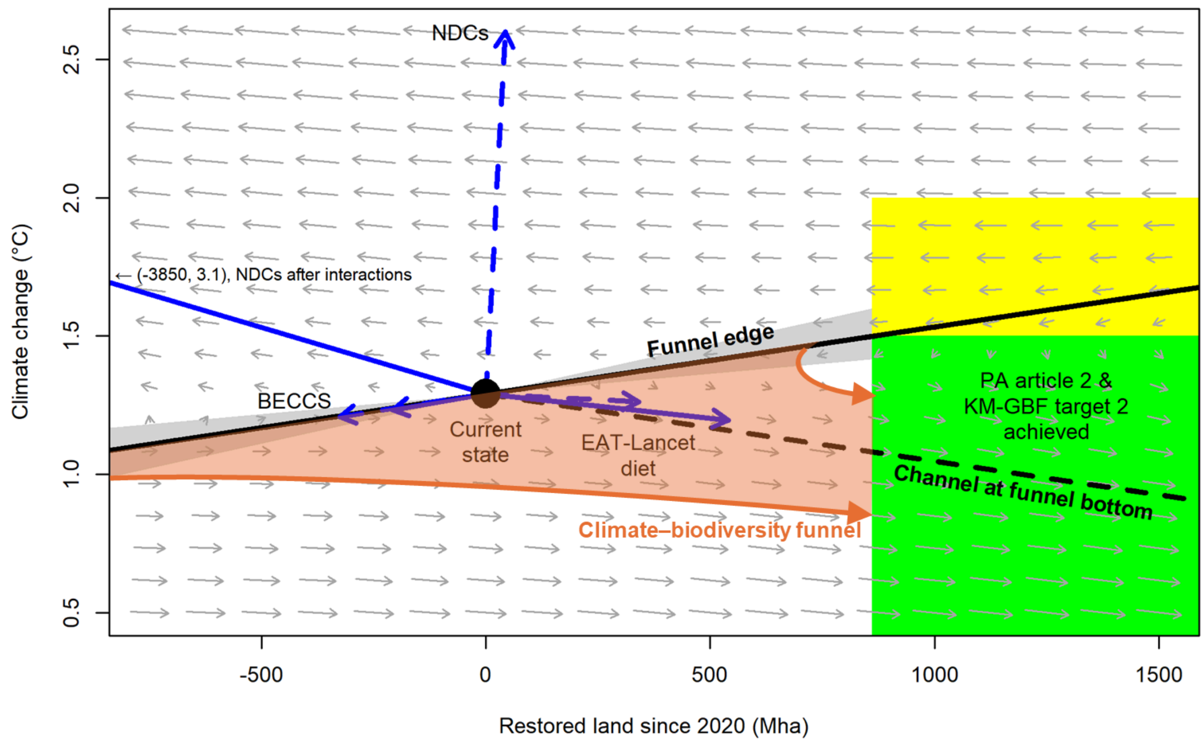

Figure 2: A climate-biodiversity funnel that accelerates action towards achieving PA Article 2 and KM-GBF Target 2. Climate and restoration actions below the funnel edge (solid black lines with grey uncertainty range) are accelerated by interactions (as indicated by grey arrows) towards achieving these global goals (green and yellow rectangles for 1.5 and 2°C limits, respectively). The greatest acceleration occurs along the funnel bottom (dashed black line). Climate and restoration actions (dashed blue lines) trigger interactions (in the direction indicated by the grey arrows) that result in potentially substantially different results for climate and biodiversity (solid blue lines). The current state of climate (black dot) is 1.29°C warming as of 2024[16].

Discussion

Our analysis shows that (a) many interlinkages between climate and biodiversity are explicitly or implicitly recognized in the PA and KM-GBF texts and (b) these interlinkages can have important dynamic consequences, including the emergence of a 'climate-biodiversity funnel'. We distinguished between interactions involving pressures and states of climate and biodiversity, showing that both are recognized in the agreement texts, but that it is state interactions that generate emergent dynamics like the funnel.

We caution that our estimates of interaction strengths are uncertain and rely on globally aggregated values. Ecosystems are highly heterogeneous; climate and biodiversity outcomes can be affected by local factors such as ecosystem type, socioeconomic constraints and biophysical processes like altered evapotranspiration and surface roughness. Further research is needed to constrain these estimates. Our results illustrate general global patterns and may not currently be suitable for informing local policy decisions. We have also omitted explicit consideration of other dimensions of the Earth system and human activity such as water and the food system, which could be strongly affected by ecosystem restoration[2]. Interactions with goals expressed by other international agreements are also important, such as the UN Convention to Combat Desertification[17]. Our analysis also does not account for nonlinearities, dynamics such as time lags or aquatic ecosystems.

Restoration of 30% of degraded lands per KM-GBF Target 2—which in our analysis corresponds to 861 million hectares (Mha), an area larger than Brazil—will likely impact food security under current food systems. These tradeoffs, but also potential synergies, between biodiversity and food production are considered elsewhere[2]. Moreover, biological carbon sequestration is inherently time-limited, with sinks created by ecosystem restoration saturating over time and potentially releasing carbon thereafter[18]. While ecosystem restoration may be helpful on policy-relevant time scales, ecosystem restoration therefore cannot balance fossil fuel emissions in the long term[19]. We also note that the time taken for restoration action to accumulate carbon will also likely be too slow to avoid transgressing the 1.5°C PA goal[20] and exceeding the "well below 2°C" PA ambition.

We offer the climate-biodiversity funnel instead as (a) an illustration of complex climate-biodiversity dynamics and (b) the estimated threshold at the edge of the funnel (approximately 0.5 $GtCO_2$ emissions per Mha ecosystem restored) as a heuristic to inform global policy and negotiation, in the spirit of other integrative boundaries and targets. This heuristic sets an ambition level for upcoming round 3 NDCs, for example. Commitments within the funnel will trigger positive feedback in the right direction for achieving PA article 2 and KM-GBF target 2. Of the policies we examined here: round 2 NDCs are well outside the funnel and trigger undesirable feedbacks; the EAT-Lancet diet is well inside and therefore triggers desirable feedbacks; and the BECCS scenario considered here is on the edge and therefore does not benefit from any beneficial feedbacks towards the goals. We emphasize, however, that the funnel does not define what is universally "good" or "bad"; real-world decisions must weigh many other considerations. Reaching global goals will likely require a combination of approaches both inside and outside the funnel.

Beyond such heuristics, integration of climate and biodiversity governance is urgently needed to ensure climate and biodiversity are systematically addressed and resources efficiently used[2,21]. The climate-biodiversity funnel demonstrated here is one of many potential dynamic phenomena emerging from the complex interplay of climate and biodiversity[2]. The fact that the KM-GBF and PA recognize such important interactions between climate and biodiversity, as we showed, provides a basis for formally integrated action. One such mechanism could be a joint UNFCCC-UNCBD work programme for climate, nature and people[22]. The recent IPBES-IPCC co-sponsored workshop on biodiversity and climate change[3] is a positive step in this direction. At national and local levels, where climate action and biodiversity conservation are also often addressed separately, integrative spatial planning is a tool that could further enhance joint action.

We view the growing interest of ecosystem-based adaptation (EbA), a focus of the upcoming COP30, as particularly important from the perspective of the interactions considered in our analysis. Co-benefits of climate mitigation actions for biodiversity, in the form of nature-based solutions, have been recognized for some time. EbA's focus, on the other hand, is on reducing the negative effects of climate on ecosystems and people. This focus recognizes that climate change is accelerating and action is needed to mitigate the effects of changes in the state of climate on biodiversity.

Conclusion

The PA and the KM-GBF are the results of the UNFCCC and UNCBD signed by all countries in the world nearly 35 years ago at the 1992 Rio Conference. So far these global and legally binding UN Conventions have failed. While the PA and KM-GBF are bold statements, providing high-level reference for policy action, they have so far not delivered on their promise. Our analysis offers avenues for integration and synergies between climate and biodiversity policy, which in turn can help the much needed transition from negotiating commitments to delivering progress against globally agreed targets. Our results show that policy synergies and trade-offs between climate change and biodiversity are real and need to be addressed simultaneously, decisively focusing on solving the dual global climate and biodiversity crises. More research is needed, but we also show that pathways towards effective policy implementation towards a safe future at COP30 and beyond are available.

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Table S1: References to climate or biodiversity in the KM-GBF or PA, respectively. We distinguish whether the reference is explicit (solid line) or implicit (dashed line), whether the reference is expressed as a pressure (top circle) or state (bottom circle) interaction and whether the reference involves biodiversity change causally affecting climate change (green line) or vice versa (blue line).

KM-GBF Target or PA Article	**Type of link** **- implicit vs explicit** **- pressure vs state** **- direction of causal relationship**	**Excerpt from PA or KM-GBF (with <u>our emphasis</u>)**
PA Preamble	Explicit Pressure Climate → biodiversity	"*Noting* the importance of ensuring the integrity of all ecosystems, including oceans, and the protection of <u>biodiversity</u>, recognized by some cultures as Mother Earth, and noting the importance for some of the concept of "climate justice", when taking action to address climate change,"
Article 4: Mitigation and NDCs	Implicit State Biodiversity → climate	"(1) In order to achieve the long-term temperature goal set out in Article 2, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, … so as to achieve a balance between anthropogenic emissions by sources and <u>removals by sinks of greenhouse gases</u> in the second half of this century…"
Article 5: GHG sinks and reservoirs	Explicit State Biodiversity → climate	"(1) Parties should take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases as referred to in Article 4, paragraph 1 (d), of the Convention, including <u>forests</u>. (2) Parties are encouraged to take action to implement and support...: policy approaches and positive incentives for activities relating to reducing emissions from deforestation and forest degradation, and <u>the role of conservation</u>, sustainable management of forests and <u>enhancement of forest carbon stocks in developing countries</u>; and alternative policy approaches, such as joint mitigation and adaptation approaches for the integral and sustainable management of forests, ..."
Article 7: Adaptation and NDCs	Explicit Pressure, climate → biodiversity and State, biodiversity → climate	"(2) Parties recognize that adaptation is a global challenge faced by all … and that it is a key component of and makes a contribution to the long-term global response to climate change to <u>protect people, livelihoods and ecosystems, …</u> (5) Parties acknowledge that adaptation action should follow a country-driven, gender-responsive, participatory and fully transparent approach, taking into consideration vulnerable groups, communities and <u>ecosystems</u>, …

		(9) Each Party shall, as appropriate, engage in adaptation planning processes and the implementation of actions, … which may include: … (e) Building the resilience of socioeconomic and ecological systems, including through economic diversification and sustainable management of natural resources.”
Article 13: Enhanced transparency framework	Implicit State Biodiversity → climate	“(7) Each Party shall regularly provide the following information: a. A national inventory report of anthropogenic emissions by sources and removals by sinks of greenhouse gases, prepared using good practice methodologies accepted by the Intergovernmental Panel on Climate Change …”
KM-GBF Introduction	Explicit Pressure Climate → biodiversity	Point 2: "…The direct drivers of change in nature with the largest global impact have been (starting with those with the most impact) changes in land and sea use, direct exploitation of organisms, climate change, pollution and invasion of alien species. …"
Target 8: Minimize the Impacts of Climate Change on Biodiversity and Build Resilience	Explicit Pressure and state Climate → biodiversity	“Minimize the impact of climate change and ocean acidification on biodiversity and increase its resilience through mitigation, adaptation, and disaster risk reduction actions, including through nature-based solutions and/or ecosystem-based approaches, while minimizing negative and fostering positive impacts of climate action on biodiversity.”
Target 11: Restore, Maintain and Enhance Nature’s Contributions to People	Explicit State Biodiversity → climate	“Restore, maintain and enhance nature’s contributions to people, including ecosystem functions and services, such as the regulation of air, water and climate, soil health, pollination and reduction of disease risk, as well as protection from natural hazards and disasters, through nature-based solutions and/or ecosystem-based approaches for the benefit of all people and nature.”
Target 19: Mobilize $200 Billion per Year for Biodiversity From all Sources, Including $30 Billion Through International Finance	Explicit Pressure Climate → biodiversity and biodiversity → climate	“Substantially and progressively increase the level of financial resources from all sources, … to implement national biodiversity strategies and action plans, mobilizing at least $200 billion per year by 2030, including by: … (e) Optimizing co-benefits and synergies of finance targeting the biodiversity and climate crises; …”

Table S2: Effects of ecosystem restoration on climate mitigation.

Reference	Interaction strength ($GtCO_2$ /Mha)	Justification	Assumptions
Tölgyesi et al.[23]	0.12	28.76 million km^2 available for ecosystem restoration for forest, shrubland, grassland & wetland, sequestering 96.9 GtC by 2100	Prioritising 20% of highest potential sequestration area to start by 2030 & remaining 80% implemented evenly 2031–2100. Current climate maintained.
Fesenmyer et al.[10]	0.34	195 Mha available for reforestation with 2225 $TgCO_2e$ per year total net mitigation potential for the first 30 years of regrowth (reduced to 1428-1591 $TgCO_2e$/yr on 116-158 Mha when avoiding social conflict)	Reforestation only. Accounts for albedo changes and regions with frequent fires. Excludes cropland.
Strassburg et al.[13]	0.54	465 $GtCO_2$ stored for restoration of 30% of currently degraded lands.	Multiple ecosystem types, including wetlands.
Zheng et al.[12]	0.33	Loss of 1.034, 1.691 and 2.059 $GtCO_2$/yr potential emissions reductions over 30 years arising from 101, 150.7 and 186.2 MHa, respectively, urban and cropland area expansion under SSP1, 2 and 3, respectively.	Opposite scenario: Loss of ecosystem area
Kemppinen et al.[24]	0.15	Reforesting 369 Mha of degraded tropical forest could sequester 5.5 $PgCO_2e\ yr^{-1}$ in the 10 years to 2030.	Tropical forest only
Littleton et al.[25]	0.10 (0.31 for reforestation only)	93 GtC captured for 3259 Mha restored (for reforestation, 29 GtC captured for 344 Mha restored)	Uses dynamical global vegetation modelling for forest restoration and agricultural regeneration
Dooley et al.[20]	0.20	103 GtC removed per total 1933 Mha restoration	Potential for land removals, including agriculture strategies
Griscom et al.[26]	0.43	Sequestration 322 $GtCO_2e$ over 753 Mha available from reforestation, coastal wetland restoration and peatland restoration over their respective minimum saturation periods.	Filters out boreal regions due to albedo.
Average	**0.28**		
Range	**0.10-0.54**		

Table S3: Effects of climate mitigation on ecosystem restoration

Scenario	Pereira et al.[27]	Schipper et al.[28]
	Global habitat extent losses for plants, no dispersal, difference between land use + climate change and land use only over period 2015-2050[29]	Global area-weighted mean MSA losses for plants due to climate change, over period 2015-2050
Raw data		
SSP1xRCP2.6	7.69%	10%
SSP3xRCP6.0	9.17%	13%
SSP5xRCP8.5	15.0%	15%
Scaled data (Mha)		
SSP1xRCP2.6	779	1013
SSP3xRCP6.0	929	1317
SSP5xRCP8.5	1520	1520
Interaction strength (Mha/°C)		
SSP1xRCP2.6	2656	3453
SSP3xRCP6.0	1561	2213
SSP5xRCP8.5	1375	1375
Average across scenarios (Mha/°C)	1864	2347
Average across papers	2105 (range 1864-2347) Mha/°C 0.95 (range 0.84-1.06) Mha/GtCO_2e	

Table S4: Large-scale policies involving ecosystem restoration and/or climate mitigation.

Policy name	Restoration action	Climate change (°C)
NDCs	43 Mha[30]	2.6°C above pre-industrial[31], equivalent to 1.31°C above current
BECCS	Natural ecosystem area loss of 325.8 Mha, assuming a scenario where existing agricultural land is not used but the land-system change, blue water and nitrogen planetary boundaries limits acceptable forest conversion[32]. This is a mid-range scenario between no planetary boundary constraints (1940 Mha) and four planetary boundary constraints (51 Mha).	6.1 $GtCO_2$/yr sequestration for same scenario described to left[32]. Using a 30 year time frame and the TCRE gives -0.082°C mitigation.
EAT-Lancet diet	Release of 340 Mha agricultural land[15]	2.1 $GtCO_2$/yr sequestration[15]. Using a 30 year time frame and the TCRE gives -0.028°C mitigation.

Analysis

Let C be the level of climate change (change in global mean surface temperature since pre-industrial, $^{\circ}C$), E be an amount of warming arising from emissions, B be the change in area of degraded lands since 2020 (Mha; positive number denotes less degraded land) and R be an area of degraded lands restored by people. Regarding interactions, let a be the reduction in warming per degraded land area restored ($^{\circ}C$/Mha) and b be the increase in area of degraded land per unit climate change (Mha/$^{\circ}C$). These definitions establish the equations:

$$B = R - bC \tag{1}$$

$$C = E - aB \tag{2}$$

Solving these equations yields

$$\begin{bmatrix} R \\ E \end{bmatrix} = \begin{bmatrix} 1 & b \\ a & 1 \end{bmatrix} \begin{bmatrix} B \\ C \end{bmatrix}, \tag{3}$$

or, inverting the matrix,

$$\begin{bmatrix} B \\ C \end{bmatrix} = \frac{1}{1-ab} \begin{bmatrix} 1 & -b \\ -a & 1 \end{bmatrix} \begin{bmatrix} R \\ E \end{bmatrix} \tag{4}$$

The interaction strengths a (central estimate 1.24×10^{-4} °C/Mha) and b (central estimate 2105 Mha/°C) take the values defined above.

The eigenvalues and eigenvectors of the inverted matrix in Eq. (4) are

$$\lambda = 1 - \sqrt{ab}, 1 + \sqrt{ab}; \quad \vec{v} = \begin{bmatrix} 1 \\ \sqrt{a/b} \end{bmatrix}, \begin{bmatrix} 1 \\ -\sqrt{a/b} \end{bmatrix}$$

.

We use these equations to generate Figure 2 as follows.

- We calculate the consequences of the policies in table S4 using Eq. (4) (solid blue lines in Fig 2), where R and E are the restoration actions and emissions relative to the current state (dashed blue lines in Fig 2).

- We represent the general effects of the interactions by calculating

$$\begin{bmatrix} B \\ C \end{bmatrix} - \begin{bmatrix} R \\ E \end{bmatrix}$$

  where B and C are as calculated by Eq. (4) (grey arrows in Fig 2). We scale the arrow lengths by their square root to aid visualisation.

- From the eigenvectors, we learn that the edge and bottom of the funnel have slopes $\sqrt{a/b}$ and $-\sqrt{a/b}$ from the current state, respectively. Substituting parameters gives slopes ± 0.54 (0.32-0.80) $GtCO_2$/Mha Policies acting along the edge or bottom of the funnel will stay acting along the edge or bottom, respectively, after interactions have taken effect.

- From the eigenvalues, we learn that actions along the funnel edge and bottom will be reduced and amplified by factors $1 - \sqrt{ab} = 0.49$ (0.25-0.69) and $1 + \sqrt{ab} = 1.51$ (1.31-1.75, respectively.