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The interactions between biodiversity and climate change and the actions required to tackle both issues simultaneously and synergistically

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Headlines

- Biodiversity loss and climate change are two of the biggest and most urgent threats facing human society worldwide.
- Human activities drive both crises, but the crises also fuel one another.
- Although many solutions benefitting biodiversity can significantly contribute to climate action, and vice versa, the two are often governed by separate policy instruments.
- An integrated approach is necessary to prioritise and implement solutions that deliver benefits for climate and nature simultaneously.
- Creating a sustainable future where people and the planet can thrive will require large-scale restoration of degraded ecosystems, protection of existing habitats and reduction of demand for natural resources, supported by policy measures that address the primary socioeconomic drivers.

Executive Summary

Human activities are unequivocally the primary driver of global biodiversity loss[1] and climate change[2], two of the main threats to human welfare and prosperity[3]. Land-use change and direct exploitation of wildlife have been the dominant global drivers of biodiversity loss to date[1], but climate change is projected to become as important as these other drivers within a few decades[4,5]. Biodiversity stabilises the climate by storing and capturing greenhouse gases so loss and degradation of biodiversity can be a source of emissions through both natural processes and human actions.

Contents

Grantham Briefings analyse climate change and environmental research linked to work at Imperial, setting it in the context of national and international policy and the future research agenda. This paper and other publications are available from **www.imperial.ac.uk/grantham/publications**

Few species can evolve quickly enough to keep up with changing temperature, rainfall patterns, and frequencies of extreme weather. Most instead respond by shifting their geographic ranges and seasonal timings, to track their climatic niche[6]; but the many species that cannot track climate in this way are likely to go extinct. Climate-driven extinction or range change of one species can disrupt spatial or temporal associations between species, perturbing ecological communities and potentially prompting ecosystem collapse[7–13]. Moreover, the interconnectedness between climate and biodiversity make ecosystems vulnerable to abrupt and effectively irreversible cascades of change that further deepen both issues[14–16].

Modelling approaches agree that biodiversity loss from climate change will be substantial, especially with high levels of warming[17]. Even though current models are imperfect and incomplete, improving their most obvious shortcomings would likely make their predictions more rather than less severe[18]. While improving the models is a clear research priority, the predictions in hand, coupled with the impacts that climate change has already had, are already a strong and coherent evidence base for policy action.

The strong interlinkages between climate and biodiversity mean that supporting biodiversity through habitat protection, restoration and management can also significantly aid in climate change adaptation and mitigation[19,20]. Actions that make use of nature to tackle broader environmental and societal challenges are termed nature-based solutions (NBS), provided that they also benefit biodiversity[21]. While NBS may have an important role to play, they are far from sufficient: society must also drastically reduce carbon emissions[22–24] and the extraction of natural resources.

Current policy measures largely deal with climate change and biodiversity loss independently, which is at best inefficient, and at worst counterproductive for humanity's chance of tackling these twin crises. This briefing paper asks, to what extent and through which means do the interactions between climate change and biodiversity call for a re-think of environmental policy, planning and practice?

Curbing the biodiversity and climate crises necessitates ambitious joined-up policy frameworks. The magnitude of required changes, and genuine disagreement about how best to bring them about, must not delay action: progress is needed on multiple fronts simultaneously. Key policy considerations to set nature on the path of recovery include the need to:

- Implement a coherent set of ambitious climate and biodiversity goals interwoven with each other and with broader sustainability goals, instead of siloed goals[25]
- Replace financial incentives that negatively impact nature with legislation mandating net benefit to nature, so that an actor (e.g., business, government) responsible for any erosion of nature fully and genuinely mitigates this erosion.
- Explicitly align intergovernmental environmental agendas, and ensure cross-departmental collaboration within governments to avoid antagonistic policies and maximise the effectiveness of interventions.

Glossary

Anthropogenic: resulting from human activities.

Agricultural intensification: the process of increasing the inputs of resources (e.g., seeds, labour, fertilisers, pesticides or technologies) to increase or maintain yield per unit of agricultural land.

Biodiversity: defined by the Convention on Biological Diversity as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems."[26] (See Box 1 for further details.)

Climate change mitigation: defined by the Intergovernmental Panel on Climate Change as "human intervention to reduce emissions or enhance the [stores] of greenhouse gases."[27]

Climate change adaptation: defined by the Intergovernmental Panel on Climate Change as "process of adjustment to actual or expected climate and its effects, in order to moderate harm."[27]

Ecosystem functions: the biological, geochemical, and physical processes occurring in ecosystems that, in turn, control the flows of energy, nutrients and organic matter into, out of, and within ecosystems[28].

Ecosystem services: are the products from a subset of ecosystem functions, and are defined as the benefits to humans and societies[29–31] derived directly or indirectly from ecosystems and ecosystem functions[32]; these can be categorised into direct, indirect and ethical services. Humans directly derive and depend upon direct services including food, freshwater, clothing, medicines, and fuel. Indirect services can be regulative (e.g., water purification, climate regulation, and disease control) or supporting (e.g., soil formation and nutrient recycling). Finally, ethical ecosystem services include the aesthetic and cultural (e.g., educational, recreation and religious) aspects inherited by future generations. Ethical services may not be vital for human survival but are important for wellbeing[33–38].

Nature-based solutions (NBS): defined by the United Nations as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits".[39]

- Ensure damage is not exported abroad (particularly from the Global North to the Global South), by legislating internationally for nature-positive production that supports sustainable corporate governance and transparent supply chains.
- Improve the modelling and monitoring of biodiversity and the integration between them, to provide the robust decision support and rapid feedback on the state of nature that will allow targets to be met.

Introduction

Biodiversity loss and climate change are interconnected, global, existential threats to society unless mitigated strongly[1,2,40]. Current rates of biodiversity loss and climate change are unprecedented in human history, threatening the continued delivery of vital ecosystem services[1]. Both crises are driven by human actions, but they also fuel one another (Figure 1). As a general rule, climate change exerts additional pressures on biodiversity and the loss of biodiversity deepens climate change. Despite growing recognition of their interlinkages[41–44], policy measures have largely dealt with these twin crises independently[21,45,46]. As deeply enmeshed problems, biodiversity loss and climate change must be tackled simultaneously through integrated global systematic changes.

Species extinction rates are at least tens – and probably hundreds or thousands – times greater than the average rate over the past ten million years; and around 1 million animal and plant species are currently threatened with extinction, many within a few decades[1]. Furthermore, climate change has already increased global average temperature by about 1.1°C compared to pre-industrial levels, the warming is accelerating, and extreme temperatures and weather events such as floods and droughts are rapidly becoming more frequent[2,47].

Globally, climate change still drives less biodiversity loss than land-use change (the dominant driver in terrestrial ecosystems) and direct exploitation of organisms (which dominates in marine systems)[1]. However, the best available models project that climate change is on track to become as important as these other drivers within a few decades[4,5], whilst also altering how these and other drivers affect biodiversity. Moreover, the high level of interconnectedness between biodiversity and climate makes ecosystems vulnerable to abrupt environmental changes such as extreme weather, and to climatic thresholds even if climate change is gradual[48]. Either mechanism can produce cascades of further biodiversity loss and climatic change[14–16]. However, the complexity of these mechanisms makes it hard to quantify how close ecosystems are to such 'tipping points' (abrupt, effectively irreversible responses) in advance of reaching them.

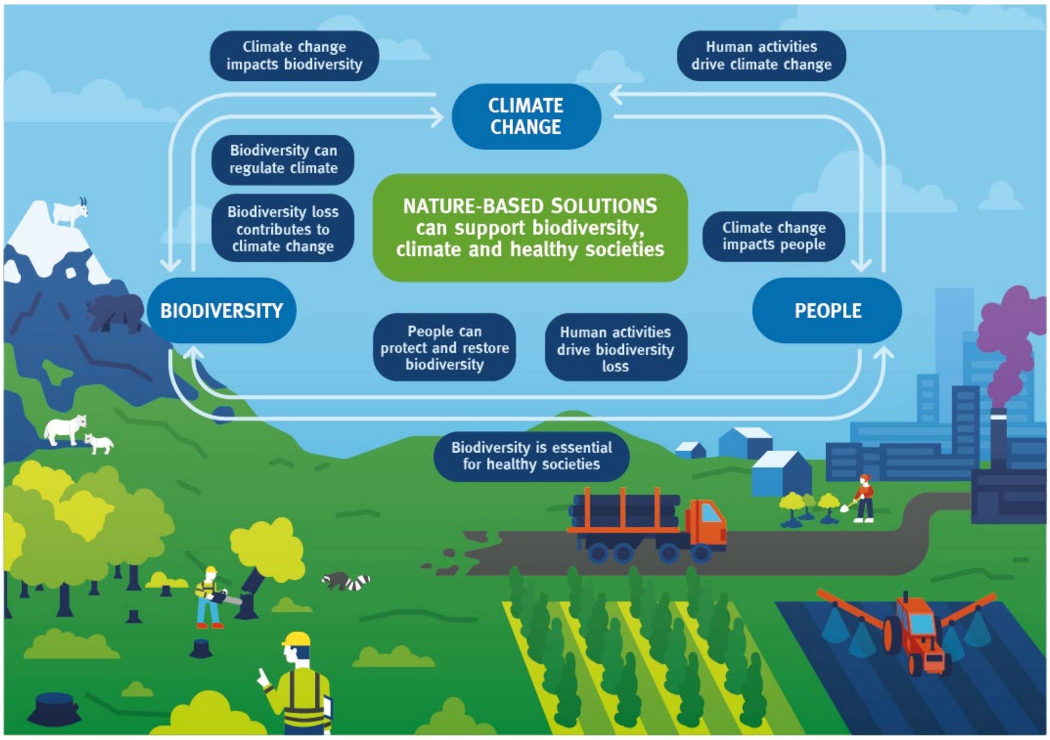

Figure 1: Interactions among terrestrial biodiversity, climate change and people. People drive climate change through, for example, burning fossil fuels. Climate change affects human society due to direct and indirect effects including more frequent extreme weather events, rising average temperatures and changes to precipitation patterns. People and biodiversity can independently mitigate and adapt to climate change within limits. Human lives and livelihoods depend on ecosystem services provided by ecosystems and the biodiversity they hold. Humans drive global biodiversity loss through processes such as land-use change and direct exploitation, but can also improve the state of ecosystems through restoration and conservation. Nature-based solutions can co-benefit biodiversity, climate action and people. Adapted from WWF, 2019[50].

Ecosystems can be protected, restored and managed to simultaneously support biodiversity, mitigate and adapt to climate change, and meet broader sustainability goals (Box 2). However, some interventions and broader policy measures can be positive in one area while undermining efforts to enhance the other, highlighting the importance of an integrated approach to maximise co-benefits to biodiversity and climate[19,20,49]. Actions that make use of nature to tackle societal and environmental challenges are termed nature-based solutions (NBS; Figure 1), provided that they also benefit biodiversity[21].

This briefing paper examines interconnections between terrestrial biodiversity and climate change. It also outlines interventions, including NBS, that can support biodiversity and climate action simultaneously, and ends with a set of policy recommendations to facilitate an integrated approach.

Biodiversity and Climate Change

Climate change and biodiversity change are not uniformly distributed across the planet. The magnitude of climate change and whether the principal change is to temperature, rainfall or extreme weather is projected to vary geographically[2] (Figure 2a-b). Rising temperatures are projected to be greatest in polar regions. At tropical latitudes, reduced rainfall is predicted to be the main effect, whilst observed and projected warming is less extreme. When considering the impact of climate change on biodiversity, the absolute change in climatic variables (temperature, precipitation) may not necessarily be as important as the relative change. For example, because temporal variation in temperature is comparatively low in tropical regions, small increases can be enough to push species beyond their thermal tolerances[51]. Moreover, species richness (Box 1) follows a latitudinal gradient, with high species richness towards tropical regions[52] (Figure 2c-d). For example, the majority of "biodiversity hotspots" are concentrated in the tropics[53]; these represent 2.3% of land surface, but contain over 75% of plant species, 43% of vertebrates, and 80% of threatened amphibians[54,55]. Hence, climate change-driven biodiversity loss is determined by the complex interplay between geographical patterns in biodiversity, magnitudes of climate change effects and other anthropogenic pressures[56].

Impacts of Biodiversity Loss on Climate Change

Global biodiversity stores and captures carbon, as well as other greenhouse gases, but ecosystems can also be a source of emissions through both natural processes and human actions. Nature naturally removes over half of annual anthropogenic carbon emissions: terrestrial ecosystems capture nearly 30% and oceans absorb about a quarter[59,60]. However, anthropogenic land-use and land-use changes can emit carbon through directly depleting biodiversity and the carbon stored within, as well as by degrading the quality of

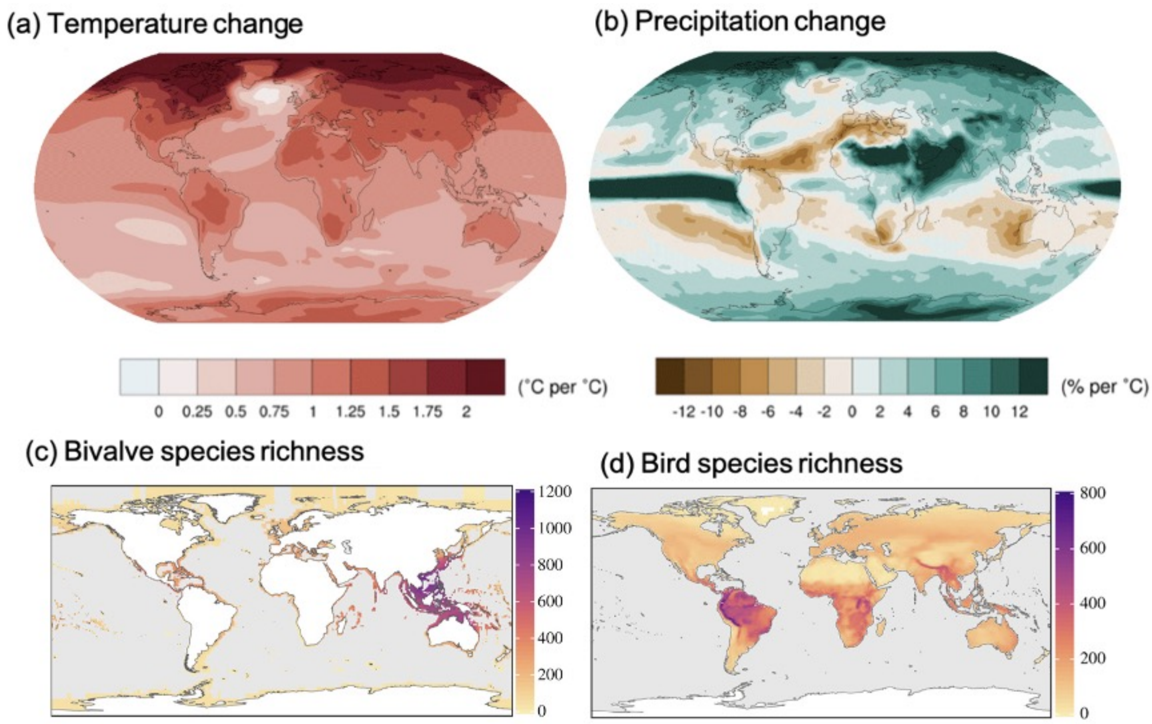

Figure 2: Projected pattern of global (a) temperature and (b) precipitation change for the period 2080-2100 relative to 1995-2014 (averaged across CMIP6 models and all Tier 1 plus SSP1-1.9 scenarios). Contemporary global species richness distribution of (c) bivalves and (d) birds. Panels (a) and (b) are adapted from Tebaldi *et al.*, 2021[57], used under CC BY 4.0/Panels a-b of the original work are displayed here. Panels (c) and (d) are adapted with permission of The Royal Society (UK), from Schumm *et al.*, 2019[58]; permission conveyed through Copyright Clearance Center, Inc.

ecosystems, examples include deforestation and peatland degradation, respectively. These land-use emissions exceed carbon capture capacities, making terrestrial ecosystems an overall carbon source responsible for over 10% of global anthropogenic emissions[59,60]. However, transformative changes to land-use through well-implemented NBS can reverse the trend, making land a net carbon sink, that can potentially capture up to 37% of the carbon emissions required to meet the Paris Agreement[61,62] (Box 2).

Biodiversity responses to climate change

Species differ in their climatic needs and dispersal abilities, meaning they are likely to respond to climate change individually, rather than as communities[11]. Many species' associations are likely to be disrupted, leading to breakdown of interactions, such as pollination, and ultimately altering entire ecosystems[51,63–65] and the delivery of ecosystem services[66,67]. In a high-end scenario with 4.5°C of warming by 2100, for example, most species would be climatically excluded from more than half of their current range[68]. Outlined below are the main mechanisms through which species and ecosystems respond to climate change.

Geographical range change: Species may respond to climate change by following suitable climatic conditions as these move geographically. A recent assessment of over 4,000 species globally found range shifts poleward or upslope for approximately half of the species[69]. However, climate-induced range changes also pose a serious threat by facilitating the establishment of invasive alien species (species that spread widely in areas beyond their native range, impacting local biodiversity and human livelihoods).

For many species, observed range change lags behind climate change, suggesting that species may be unable to reach climatically suitable regions (which must also be suitable in other ways, e.g., soil type and interacting species) with sufficient speed, with extinction the predicted result[70–73]. Distance to colonisation site, as well as differences in reproduction and dispersal, affect species' chances of keeping up with climate; e.g., plants with wind-borne seeds have better prospects than do large, flightless terrestrial animals[74,75]. Moreover, the widespread human modification of landscapes (only a quarter of land is sufficiently unimpacted for ecological processes to operate without significant human disturbance[1]) often impedes species dispersal, increasing the jeopardy that species face[76,77].

Climate change in combination with other global changes, including increased human movement, facilitates the establishment of invasive alien species[78–82]. These species' effects include reducing the abundance, genetic diversity, phenotypic diversity and species richness of native organisms, changing community composition, and directly causing native species extinctions[82–88]. They also threaten ecosystems' ability to withstand climatic changes and maintain the provision of ecosystem services[84,85,89,90], with consequences for human welfare[91]. For instance, the invasive Emerald Ash Borer (*Agrilus planipennis,* a beetle native to Southeast Asia) causes widespread mortality among North American ash trees and its spread is facilitated by rising temperatures that increase survival rates at high latitudes[92]. This invasive beetle has killed some 100 million trees to date, and threatens a further 7 billion native ash trees, which are an economically important timber product and a cultural resource to some native peoples[93]. However, invasive species' impacts are complex, difficult to predict, and may only become apparent after several years[80,82–86,94]. The negative effects of geographical range change in the form of invasive species may outweigh benefits gained by species tracking suitable climatic conditions[79,81].

Persistence: Time lags in range shift in response to contemporary climate change may, for some species, be indicative of the ability to withstand or persist through changed climatic conditions[95]. Land-cover features that provide local climatically tolerable refuges from climate extremes (microrefugia) can allow populations to persist within the landscape without geographical range change[96]. For instance, forest floor summer temperatures have not risen nearly as much as forest canopy temperatures[97]. In the areas of England with the fastest warming, research suggests that microrefugia can reduce local extinctions of plant and insect species by 22% and 9%, respectively[98]. How far, and for how long, microrefugia can buffer against future climate exposure remain unclear.

Acclimatisation, also known as phenotypic plasticity, can permit species to cope with the effects of climate change by altering individual organisms' phenotype(s) (behaviour, physiology, morphology, etc.) within their lifetime without any genetic change[99–102]. Phenotypic plasticity determines the degree to which species may acclimatise and is considered a particularly important response among species with long generation times, where evolution is unlikely to produce enough genetic change under rapid and accelerating climatic change[103]. Phenotypically plastic responses to rising temperatures include altered phenology (life-cycle timings) such as timings of breeding, spring emergence, migration dates and flowering[63,104–106].

However, acclimatising capabilities have their limits. The possible phenotypic changes and the degree to which organisms can change their phenotype(s) in response to climate change are genetically coded and may therefore be limited to the environmental conditions found across a species' range. Moreover, species may already be using the full extent of any phenotypic plasticity to respond to current climatic change[107]. Many species have evolved synchronised timings of major life cycle events, which are triggered by environmental cues such as seasonal temperature changes or amount of daylight. For example, the relative timings of key life-cycle events in interacting species have changed much more rapidly since 1980 (when climate change became rapid) than before, with ecological consequences that are often unclear[108].

Evolution: Species may be able to respond to climate change through genetic changes with phenotypic effects (i.e., evolution by natural selection)[100]. However, only species with relatively short generation lengths can evolve fast enough to track rapidly changing environments. Contemporary examples of such rapid evolutionary responses are emerging, although it is generally difficult to distinguish the relative contributions of evolution and phenotypic plasticity to observed phenotypic changes[100].

Evolutionary change is limited by the degree of existing genetic diversity; hence, genetically diverse populations are more able to evolve in response to climate change[109,110]. Furthermore, trait variation may not be heritable, so cannot always be acted on by evolution. For instance, roe deer (*Capreolus capreolus*) give birth in spring, when food resources are abundant. Although food is available earlier due to spring advancing, the timings of births has not advanced, perhaps because they cannot track environmental cues in resource availability for the timing of reproduction[111].

Extinction is the dying out of a species globally or locally. To date, there are few examples of contemporary global species extinctions that can unambiguously be attributed directly to anthropogenic climate change, although examples of local extinctions are widespread[112,113]. The current dearth of contemporary global extinctions does not suggest that biodiversity is coping with climate change. Rather, it suggests an extinction debt[a], in which species are on the path towards extinction but have not yet been pushed over the edge[8,114]. One study estimates that at least 44% of terrestrial plant and animal species have experienced local extinctions, primarily due to increasing maximum temperatures, and 55% may no longer be able to live anywhere in their current range by 2070 if warming has reached 2.6°C by then[115]. Local extinctions decrease species' ranges and genetic diversity, and in turn reduce the likelihood of avoiding global extinction through acclimatisation or adaptation.

Ecosystem tipping points and cascading effects

Ecosystems are more than the sum of their parts: species depend on complex networks of interactions with one another and the physical environment. This complexity means that the impacts of climate change on particular species or ecological processes can amplify through the ecosystem, with the potential to trigger irreversible consequences regionally and globally.

Climate change-driven effects on the distribution, abundance or phenological timing of a given species can have knock-on effects on species with which it interacts[7,8], potentially leading to the loss of multiple species through 'extinction cascades'[116]. Generally, losing key species that provide resources for many others triggers bottom-up extinctions ofhigher-level consumers[12,13].

Abrupt environmental changes, or threshold effects of gradual change, can also trigger effectively irreversible cascading effects that worsen both biodiversity and climate change[14–16,48]. Evidence for the crossing of such tipping points is beginning to accumulate[117]. One example is the accelerating thawing of Arctic permafrost due to rising temperatures. Arctic permafrost covers a quarter of the Northern Hemisphere and holds four times the amount of anthropogenic carbon emitted since industrialisation[118]; thawing releases the carbon, fuelling further climate change.

Reduced rainfall coupled with more frequent droughts and wildfires have been projected to trigger a tipping point of rapid cascading Amazon Rainforest Dieback, leaving a savannah by 2100 where the world's largest tropical forest once stood[119,120]. Although there is high level of agreement among scientists that such an event is possible, the extent and timing of cascading Amazon dieback remains uncertain and most projections estimate it to be less severe[15,121–123].

Future climate change scenarios typically focus on smooth long-term increases in global average temperature. However, biodiversity responds more directly to exceptional circumstances, such as extreme weather events, at the local or landscape scale[16]. For example, boreal forests are increasingly becoming net carbon emitters[124,125] due to large-scale pest outbreaks triggered by droughts[126] and wildfires[127,128]. Biodiversity loss under future climate change is therefore projected to be abrupt such that many species in a community are simultaneously lost in response to, for example, a heatwave[129].

Exceeding one ecosystem tipping point increases the risk of crossing ecosystem tipping points elsewhere[130] because of connecting oceanic and atmospheric processes[131–133]. There is no definitive answer to the key question of how close we are to the point at which climate change will trigger an unstoppable cascade of ecosystem tipping points: but several recent studies have suggested that we are already very close[117,131,132].

Modelling and projecting biodiversity-climate change interactions

Given the complexities of the ways climate change can drive biodiversity change, it is unsurprising that predicted impacts vary widely even among projections of the same component of biodiversity (e.g., a given taxonomic group within a given region; see Box 1) under the same scenario[18]. However, a large proportion of studies predicts substantial biodiversity loss[17]. A systematic review of 97 published projections[17] found that under a global mean temperature increase of up to 2°C, terrestrial ecosystems would lose on average 14% of their current local species richness and 35% of species range size, though both figures varied markedly among major ecosystems and taxonomic groups. For context, ecosystem functioning tends to decline significantly when species richness is reduced by 20% or more[134].

a Many drivers of extinction have delayed effects, meaning that some extinctions will happen in the future because of past events. These are termed the 'extinction debt'. The children's game of Musical Chairs provides an everyday analogy: removing a chair means that a player will have to leave the game, but only when the music stops.

Rather than rise linearly with the rate or amount of climate change, the impacts on biodiversity are likely to accelerate[135], if climate moves beyond the range that ecosystems or key species can tolerate. For instance, over 20% of global land is projected to undergo at least one abrupt ecological transition this century towards a low-nutrient, species-poor endpoint[136]. However, no generalities have yet emerged about exactly how much climate change can be tolerated before such 'tipping points' are reached, suggesting they are very context-dependent[137,138].

Other drivers are likely to form an important part of the context for climate change impacts. Most predictions of climate change effects on biodiversity have implicitly ignored effects of land-use change[139], even though it is the most important driver of biodiversity loss at present[1]. The few projections to incorporate both effects typically assume they combine additively[4]. However, each driver is likely to exacerbate the other[140]. Simple models[141] show that such synergies bring tipping points closer. Making robust quantitative predictions about proposed thresholds such as the Amazon die back[142] likely requires models much richer than those available today, incorporating synergistic effects of all relevant drivers.

The best predictions currently available suggest that climate change will become as important a driver of biodiversity loss as land-use change within the next few decades, likely disrupting ecosystem services[5,17] by, for example, pushing many drylands beyond near-irreversible thresholds[136]. Fixing the most obvious shortcomings of today's models would probably make their predictions more rather than less severe[18]. While improving the models is a clear research priority, the predictions already in hand, coupled with the impacts that climate change has already had (see previous section), already represent a strong and coherent evidence base for policy action.

Box 1: The diversity of biodiversity

The term *biodiversity* encompasses much more than species numbers; it refers to the sum of variation among and within all life on Earth (Figure I). From amoebas to antelopes, chimpanzees to chilli plants; their genetic variation, behavioural differences, geographic distributions, relative abundances, and the communities and ecosystems of which they are part[b]. Individuals within a given population vary ecologically, behaviourally, anatomically and physiologically (collectively termed phenotypically), as well as genetically; these differences constitute populations' phenotypic and genetic diversity, respectively. Species' total genetic and phenotypic diversity vary with numbers of populations and geographical distributions. Co-occurring populations of different species form communities, which differ in species richness (total number of species) and composition; moreover, species' interactions with each other and their physical environment form various ecosystems such as coral reefs, tundra and rainforests that in turn determine the rates of ecosystem processes such as pollination, net primary production and evapotranspiration. All this variation constitutes biodiversity. Hence, *biodiversity loss* and *biodiversity change* include the loss and change to any component of life on Earth, and both are leading causes of reduced provision of ecosystem services, and capacity for ecosystems to mitigate and adapt to climate change[1,143].

Figure I: Various levels at which biodiversity can be measured.

b Note that although humans are by definition part of "biodiversity", we differentiate between human and all non-human life on Earth and here, the term "biodiversity" refers to the latter.

Accepting uncertainty while seeking to reduce it

The projections of future biodiversity sketched above have three main sources of uncertainty: the biodiversity models, the data, and the future state of the drivers of biodiversity change. Limitations of current modelling frameworks are outlined above, but the data used to fit them are often spatially incomplete (e.g., part of a species' geographical range)[144]. The fitted models – each with inherent uncertainties[145] – are then integrated with a range of climate change-projections derived from narratives of plausible future scenarios 'translated' by another set of complex models of atmospheric and oceanic processes. The narratives for future socio-economic and technological developments, as well as societal values and political priorities, driving climate change are also intrinsically uncertain[146]. However, policymakers routinely make choices in the absence of certainty as to the full range of consequences. To facilitate policymaking and make the risks inherent in all comprehensive legislation more manageable, scientists must accurately communicate and, where possible, quantify uncertainties and risks[147–150].

In the longer term, better data about past biodiversity can reduce uncertainties about the future. Even in the United Kingdom, which is unusually well-documented, detailed knowledge is limited to the period since 1970[151], postdating most large-scale landscape transformations[152–154]. This period is too short to reveal whether there are general patterns or whether recent trends are idiosyncratic, and constrain estimates of the separate and combined effects of different pressures[144,155,156]. Extending climate observations back before the instrumental record (through use of data from such sources as tree rings and ice cores) and even into deep time (using paleoenvironmental proxies) drove improvements in climate models. In the biodiversity domain, the main opportunities for extending the record backwards are the digitisation of specimens in natural history collections[157,158] and text-mining relevant old literature[157,159]. Despite recent statistical advances allowing for the use of unconventional data such as natural history collection specimens[158,160–162], most such data are locked in undigitised specimen labels and unpublished archives and notebooks. These early biodiversity data can provide a unique view of biodiversity change through the Anthropocene. Techniques exist to mobilise them[163], but resource is lacking.

Actions to benefit climate, biodiversity and ecosystem services

Human activities are unequivocally the main driver of contemporary biodiversity loss[1] and climate change[2], which in turn, threatens human welfare and prosperity. Reversing current trends is therefore urgent. Whilst supporting biodiversity, NBS can significantly aid in climate adaptation and mitigation, especially if designed to fully exploit co-benefits[19]. However, individual NBS will vary in the relative benefit to nature, to climate, and the timescales over which those benefits accrue. Hence, their implementation must consider multiple short- and long-term outcomes simultaneously and be supported by environmental standards and laws to safeguard the delivery of benefits. This section outlines three broad NBS that simultaneously address biodiversity loss and climate change, and concludes by outlining how reducing the demand on nature is key to scaling-up NBS.

Ecological management of agricultural land

Although historical expansion and intensification of agricultural land[c] gave rise to improved human health and prosperity, current resource-intensive agricultural practices present the single largest driver of biodiversity loss[29,164]. However, with appropriate management, many agricultural landscapes can support higher levels of biodiversity than at present while contributing to climate mitigation and adaptation.

Conversion of natural and semi-natural land to agriculture leads to often irreversible loss of biodiversity and carbon storage capacities[165], so should be avoided; and chemical/mechanical inputs to agriculture should be replaced with ecological inputs wherever possible[166,167]. Agriculture already occupies around half of Earth's habitable surface[168]; if managed sustainably, this would comfortably suffice for global food security (especially with dietary change; see below). Moreover, cropland productivity has increased by 350%[143] since 1950, enabled by massive intensification including an eight-fold rise in chemical fertilizer input[169] and doubling of pesticide use[170]. Contemporary agricultural intensification methods have few benefits; although per-area yields temporarily increase, the ecosystem services supporting long-term productivity decrease[171]. For example, pesticides impact wildlife populations negatively, including species providing services such as pollination and natural pest control upon which agricultural systems depend[170]. Shifts to organic and other ecologically managed agroecosystems can support both directly beneficial biodiversity and biodiversity at large, and at the same time improve carbon storage and capture[172–174].

Reversing current trends towards simplified agricultural land in favour of heterogenous landscapes benefits nature and farming simultaneously[172]. Conventional agricultural land is increasingly homigenized through, for example, the removal of wildlife habitat patches (e.g., hedgerows) and cultivation of single crop species (monocultures). Replacing monoculture systems with diverse crop cultivation increases carbon storage capacities by up to 67%[175] and can double productivity[176,177]. Similarly, multifunctional landscapes that support nature, climate and crop productivity can be produced by converting no more than 20% of agricultural land to semi-natural habitat[178] (land sharing). However, not all species can thrive in ecologically managed agricultural landscapes; safeguarding less tolerant species will require "land-sparing" (land where biodiversity is the priority).

c Here, agriculture refers to cropland and grazing land for livestock; but note that forestry can be considered agriculture, and with appropriate management, can support high levels of biodiversity as well as providing climate change mitigation and adaptation.

Proactive supportive policies must underpin transformative changes toward sustainable agricultural systems[119,179]. First, removing subsidies for environmentally damaging agricultural practices and instead subsidising nature-positive practices will help to accelerate the transition to sustainability[180]. Second, taxing damaging practices and ensuring the polluter (or degrader) pays will increase costs to unsustainable producers. However, to ensure local producers have a level playing field and to avoid the offshoring (i.e., relocating) of damaging agricultural practices, countries are likely to need to impose tariffs on imports from areas with lower environmental standards[172,181,182]. Finally, most publicly financed research and development currently focusses on high-intensity agriculture, effectively subsidising damaging practices; these funds should be reallocated to research into sustainable agriculture[183].

Many changes towards sustainable agriculture will reduce yield per unit area[184]. However, by reducing demand for resource-intensive foods (e.g., meat and dairy; Figure 3) and considering the long-term yields per unit of natural resource degradation, all current agricultural land can be managed agroecologically while still feeding the growing human population[185].

Environmental protection

Effective area-based protection from destructive human activities is key to halting biodiversity loss, and provides significant climate mitigation and adaption[1,187–189]; yet, the majority of areas harbouring high levels of biodiversity and carbon globally remain unprotected[190]. Intact ecosystems are of particular importance: despite having higher levels of biodiversity[191,192], as well as carbon capture and storage capacities compared to degraded equivalents[193], only a tenth of the 3% of terrestrial ecosystems estimated to remain faunally intact are formally protected[194]. Intact areas urgently require formal protection[195–197]; however, a large proportion of ecosystems altered by humans also need protection.

Protecting a variety of ecosystem types will yield the greatest benefits to biodiversity[198]. Tropical rainforests harbour over half of Earth's species[199,200], and collectively account for more carbon in living biomass than any other ecosystem[201]. Over the past 20 years, depletion (primarily driven by agricultural expansion[202]) has reduced tropical rainforest coverage from around 10% to 6.5% globally[203]. Today, around 30% of these forests are formally protected[202]; protecting the remaining forests is critical for preventing further biodiversity loss[204] and ensuring stable aboveground carbon stores[205]. On the other hand, natural grasslands offer more reliable long-term climate benefits compared to tropical forests because their carbon is primarily held in soil, which is more resilient to droughts and fires[206]. Hence, protected areas should represent diversity among ecosystem types.

Restoration of natural habitat

Around 75% of Earth's terrestrial land and 40% of oceans are extensively altered by human activities[1], maintaining the state of remaining areas through protection will not deliver sufficient change to reverse the biodiversity and climate crises. Instead, ecosystem restoration is necessary in a significant proportion of anthropogenically altered areas[1,143,207], coupled with some form of protection to ensure long-term delivery of benefits. As an example, a recent study found that targeted restoration of 15% of global agricultural land could avoid up to 60% of expected species extinctions and capture 30% of post-industrial carbon emissions[208].

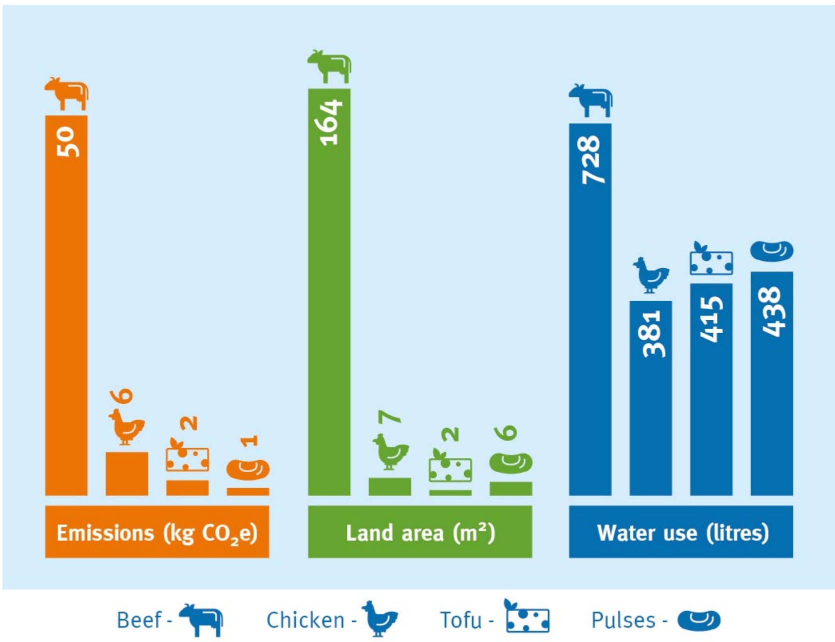

Figure 3 Average greenhouse emissions (kg), as well as land area (m²) and freshwater (l) needed to produce 100g of protein from beef, chicken, tofu and pulses. Based on data from Poore & Nemecek, 2018[186]. Note that variation in emissions, land area and water-use within each of the four food groups is not displayed; however, variation between high- and low-resource food groups (e.g., beef and tofu) outweighs variation within groups.

There are considerable trade-offs to take into account when defining the best approach for ecosystem restoration. Upon the removal of anthropogenic disturbances such as pollution or agriculture, ecosystems can naturally regenerate (passive approach) or be actively restored (e.g., by tree planting)[209,210]. Active and passive restoration generally show similar rates of carbon storage recovery, but biodiversity may recover faster following costlier active approaches, particularly for rare and endangered species[211,212]. However, rates of recovery are contingent on the ecosystem context; for example, passive regeneration can restore tropical forests' carbon storages to pre-disturbance levels in 70-120 years[213,214], whilst peatlands can take 500 years or longer to recover passively[215]. Moreover, trade-offs are often complex and difficult to predict, as demonstrated in passively regenerating Norwegian forests. Following the removal of livestock, moose and other large herbivores recolonised the forests, which shifted the dominant type of herbivory from grazing to browsing (i.e., low- to high-growing vegetation), resulting in reduced total aboveground vegetation and carbon storage[216,217]. However, plant species diversity increased and, unexpectedly, the modified vegetation structure reflected more solar radiation (higher albedo), limiting warming[218].

Ecosystem restoration can provide socioeconomic co-benefits, particularly in human-dominated landscapes. For instance, in response to upstream river degradation compromising New York City's source water quality[219], a $1 billion river restoration project to provide natural filtration was chosen over constructing a water treatment plant[219]. This exemplifies a NBS providing co-benefits for (1) biodiversity, (2) adaptation because of wetlands' natural flood prevention capacities, (3) mitigation through carbon capture, and (4) human mental health and wellbeing by encouraging connection with nature[33–38], whilst costing $5 billion less than contracting a treatment plant[219].

Reduce demands on nature

Natural resources are used at rates that far exceed Earth's ability to supply them and unsustainable resource extraction has driven over 90% of recent global species extinctions and around half of anthropogenic emissions[220]. Direct exploitation of wildlife – for medicine, pets, ornaments and food – is a growing driver of biodiversity loss in terrestrial systems and the main driver of biodiversity loss in marine systems[1]. Moreover, demands for natural resources tripled since 1970, predominantly driven by economically developed countries[220–222]. Supplying everyone with the resources used by the average UK resident, for example, would require three Earths[223].

Wealthy countries' excessive demand is increasingly met by importing natural resources from lower-income countries. For instance, over 95% of Switzerland's environmental consumption impacts occur abroad[224]. On a global level, resource extraction and processing is associated with 19 million premature deaths per year. Around 6.5 million of these deaths are linked to adverse health effects of air pollution (from transport emissions, dirty cooking oil, etc.), including lung cancer and cardiovascular diseases[225] and, as lower-income countries commonly host higher levels of biodiversity, these countries are often left to pay the environmental and humanitarian price for wealthy countries' demand. Moreover, additional income and consumption ceases to contribute toward life satisfaction beyond specific thresholds, but a significant proportion of the human population consume above these thresholds[226–228]. This proportion, in particular, *must* learn to live with less.

Reduced consumption of animal-based products presents a major opportunity without compromising food security (including for the projected human population growth by a further 2–3 billion people by 2100; Figure 3)[229,230]. The area used to raise livestock (including the area used to grow fodder) approximates the size of North America and South America combined[231], and around 15% of anthropogenic emissions stem from livestock[232]. Furthermore, over-consumption lowers human life expectancy by increasing incidences of chronic diseases such as coronary heart disease and cancer[175,233]; still, individual consumption of red meat in Europe and North America exceeds national recommendations by 300-600%[234,235]. Hence, shifts to plant-based diets can reduce environmental impacts whilst benefitting human health.

The Urgency of Action

The 'Tragedy of the Horizon'[236] represents a major obstacle to implementing costly policies that are necessary to prevent environmental disaster: because the disaster is beyond most political or financial planning horizons, delaying action always appears cheaper than taking action in the short term. This is especially the case given that the biophysical processes by which more carbon is stored and biodiversity recovers are slow. For example, during re-growth of tropical forests, aboveground carbon storage takes an average of 80 years to recover to natural levels and, even then, the species that characterise undisturbed forest are still mostly absent[237]. Our limited understanding of how climate change will affect these biophysical processes adds an additional layer of uncertainty that might be used to further justify delay.

However, available evidence strongly suggests any delay in investment would be a false economy. Comparison of two scenarios – one with immediate action and one with a decade of delay – suggests that delay roughly doubles the cost to governments (i.e., the social cost) of achieving net zero greenhouse gas emissions by 2050[238] and of 'bending the curve' of biodiversity loss by 2050 (returning the global average state of local biodiversity back to 2020 levels)[239]. These differences imply an annual return on immediate investment of around 8%. As well as being a false economy, delaying action on biodiversity also leads to an increase in relative food prices and may make the targets biophysically unachievable[239].

Future Biodiversity and Climate Policy

Curbing biodiversity loss and climate change necessitates ambitious joined-up policy frameworks with sufficient rigour, oversight, and resource to implement major systematic changes. The magnitude of necessary changes, and genuine disagreement about how best to bring them about, must not delay action: progress is needed on multiple fronts simultaneously. The following recommendations to set nature on the path of recovery highlight NBS with biodiversity-gains, where co-benefits tackle climate change, but note that these must be deployed alongside drastic reductions in carbon emissions[22–24]. Moreover, the recommendations aim to aid stakeholders across society (policymakers, the private sector, individuals, scientists, etc.) to jointly implement effective interventions and overcome common obstacles.

Actions to target multiple goals simultaneously

Current policy frameworks tend to focus on linear causes-and-effects, with sets of action-based targets (e.g., net-zero carbon emissions) organised under one apex goal (e.g., <2°C warming; Box 2). Action-based targets are particularly problematic for biodiversity because they generally only address one facet of biodiversity, which can incentivise progress at the expense of other facets. Although action-based targets may be the most appropriate for near-term milestones (because biodiversity does not respond immediately to actions such as habitat restoration), biodiversity needs outcome-oriented targets for the long term if it is to be safeguarded.

Several top-level biodiversity goals have been proposed as umbrella targets, that would ensure, or at least keep open, the possibility of reaching the Convention on Biological Diversity (CBD) 2050 vision of living in harmony with nature (Box 2). Proposals have variously focused on wilderness[240], setting aside half of the planet for nature[241], and bringing the rate of species extinction down to more natural levels[242]. Although achieving each of these goals would benefit the state of nature, none would guarantee even the possibility of reaching the 2050 vision; this is because the different facets of biodiversity (Box 1) vary too independently for any to act as an effective proxy for the rest[25,243].

A single quantitative goal would be bad for nature and people[25]; instead, there is need for a coherent set of ambitious goals interwoven with broader Sustainable Development Goals (SDGs; Box 2), implemented with sufficient rigour, oversight and resource[244]. Because the facets of biodiversity are not wholly independent, there will be many opportunities for policies to be designed so as to deliver progress towards multiple biodiversity goals[243]. Policies must therefore facilitate and upscale solutions as well as ambitious transformative changes to demand on natural resources, many of which will simultaneously benefit other SDGs.

Integrated political agendas

Issues like biodiversity loss and climate change, which are global in scale and impact, require continuous international negotiation and increasingly ambitious multilateral agreements. For instance, the United Nations Framework Convention on Climate Change (UNFCCC) 26th Conference of the Parties (COP26) (Box 2) demonstrated the willingness of developing countries to reduce emissions and halt deforestation in return for a commitment among rich countries to discuss the idea of reparations (for damage caused by historical emissions). This kind of *quid pro quo* would not be possible without COPs (or something very similar).

However, the agendas of UNFCCC and CBD must be aligned through increased collaboration to enable a unified approach, which weighs NBS' trade-offs to deliver efficient policies that avoid progress towards one target inflicting unnecessary costs to others[243]. Intergovernmental strategies to tackle climate change and biodiversity loss are formulated by separate conventions (UNFCCC and CBD, respectively) with individual scientific panels to collate and present the information that guides decision-making (Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), respectively; see Box 2). Much of the membership of CBD and UNFCCC is shared, but there is relatively little communication between the conventions. Although a Joint Liaison Group (JLG) established 2001 explicitly aimed to increase coordination, mediate exchange of information and highlight opportunities for synergistic strategies between the conventions, it meets relatively infrequently and has not succeeded to align the conventions' agendas sufficiently. CBD and UNFCCC need to converge through clearer declarations of mutual support, which could, for example, be achieved by strengthening the authority of the JLG.

Local, regional and national governments must align departmental agendas through increased cross-departmental collaboration to enable efficient implementation of NBS and reduce the risk of antagonistic policies. Large-scale shifts, for example, towards plant-based diets in countries with diets rich in animal-derived calories, require a whole-of-government approach to incentivise stakeholders within agriculture, forestry, etc., while also providing all citizens with the education and financial means to make positive choices for themselves, society, and nature[230].

Box 2: International environmental policy frameworks

Three main United Nations-facilitated multilateral policy frameworks aim to address issues concerning climate and biodiversity, and broader sustainability questions. However, there has been inadequate progress on all three frameworks (Figure II).

The Convention on Biological Diversity (CBD) is an international agreement for biodiversity. The **Strategic Plan for Biodiversity 2011-2020**[245], a ten-year framework aimed to improve the state of global biodiversity and safeguard ecosystem services, was adopted by CBD's 196 member states at its tenth meeting of the Conference of the Parties (COP10). The Plan consists of 20 targets (the Aichi targets) organised under five Strategic Goals. However, not a single target was fully achieved by 2020[164,246]. Around one third of the targets showed worsening trends, especially targets to address and reduce drivers of biodiversity loss. Some progress was made towards the remaining targets, with most improvement relating to policy responses, sustainable resource-use and quantitative area-based protection[247]. The 2011-2020 framework received critique for ambiguous wording and largely unquantifiable targets, likely resulting in alternative interpretations[248–250].

The **Post-2020 Global Biodiversity Framework** is due to be finalised in December 2022 (the COVID-19 pandemic caused a two-year postponement), during the **15th meeting of the Conference of the Parties (COP15) in Montreal, Canada.** The framework aims to act as a steppingstone towards CBD's commonly agreed 2050 Vision of "Living in harmony with nature", where by 2050, "biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people."[251] Analyses of the largely unsuccessful 2010-2020 framework (Figure II) suggests that, to maximise accountability and the chances of delivery, new goals and targets should be quantifiable and associated with substantial and measurable actions[252]. CBD COP15 presents a major opportunity for international attention on the interdependence of biodiversity, climate and people (Figure 1). A good outcome of COP15 would be a Paris-style comprehensive global agreement on biodiversity that is legally binding, holding nations accountable if shares are not fulfilled.

United Nations Framework Convention on Climate Change (UNFCCC) is a treaty, currently ratified by 198 states, to combat anthropogenic climate change. During its 21st meeting of the Conference of the Parties (COP21) in 2015, member states adopted **the Paris Agreement**[253]: a legally binding agreement to limit average global temperature increase to well below 2°C, preferably 1.5°C, compared to pre-industrial levels. As the first binding agreement of its kind, it represents a landmark in international efforts to mitigate and adapt to climate change. Ratifying states agree to periodically submit increasingly ambitious commitments to reduce national emissions and build adaptation (Nationally Determined Contributions; NDCs) in accordance with detailed guidance set out in the 'Paris Rulebook'. Six years later, agreement on the common rules to limit emissions was reached at the 2021 26th Conference of the Parties (COP26) in Glasgow, United Kingdom. COP26's outcomes were mixed. On one hand, the final agreement is insufficient to limit warming to 1.5°C, and unlikely to even keep warming below 2°C. On the other hand, any reduction in emissions reduces the degree of future warming[254]. Despite the slow pace of progress, COP26 can therefore still be considered a stepping-stone from which future COPs can improve. The 27th Conference of the Parties (COP27) will be hosted by Egypt in November 2022.

The 2030 Agenda Sustainable Development Goals (SDGs), adopted by all UN Member States in 2015[255], highlights that social, economic and environmental sustainable development must be addressed simultaneously in global partnership. The Agenda consists of 169 targets organised under 17 Sustainable Development Goals (SDGs) to be reached by 2030, wherein biodiversity is important for achieving all but one on the goals[256].

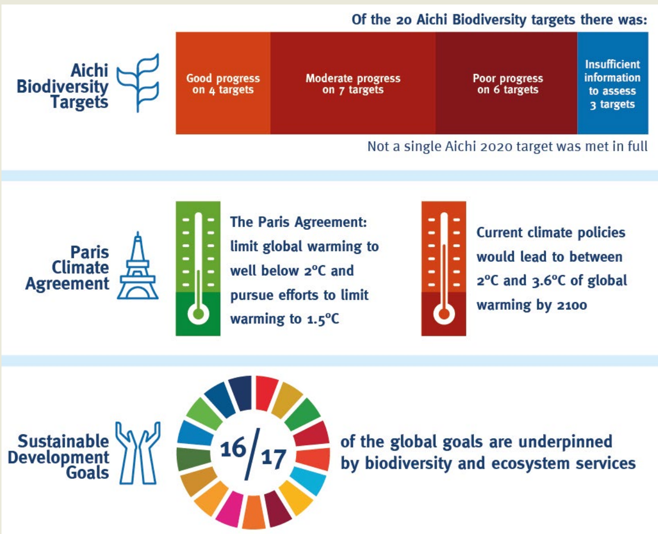

Figure II: International agreements, and global goals and targets addressing climate change and biodiversity loss.

Valuing nature appropriately

Nature is central to the global economy, yet financial support for nature is negligible compared to the financial value of natural resource exploitation[22,257]. For example, NBS could capture about a third of the carbon required to meet 2°C peak-warming[22,62,258,259], but currently receive less than 3% of climate funding[260]. The largest climate finance initiative to date, the Glasgow Financial Alliance for Net Zero (GFANZ), does not yet explicitly mention nature or biodiversity, though its co-chair Mark Carney has stated that GFANZ needs to broaden its concept of 'net zero' to include biodiversity[261]. Without effective mechanisms for funding NBS, they are unlikely to scale as rapidly as is needed.

The concept of 'natural capital' is gaining traction as a common metric to facilitate factoring nature into business and government decisions, whereby the value of benefits provided by nature are articulated in monetary terms[262]. The consequences of poorly managed natural capital therefore extend beyond accelerated biodiversity loss and climate change to include social and economic liabilities. Most attempts to value natural capital find that healthy ecosystems' price tag greatly exceeds resource exploitation[263]. For example, the worth of the Earth's combined ecosystems services is estimated to be twice that of global GDP, $125 trillion[264]. However, although natural capital establishes a framework for valuing nature, whether or not to consider natural capital as a land-use asset that can be owned, managed, and invested in to generate financial returns remains divisive[262]. Opponents argue that natural capital is best considered a non-tradable public resource since most of its value lies outside the market and cannot readily be translated into financial capital (e.g., spiritual, ethical and indirect ecosystem services)[265,266].

Legislation for nature-positivity

Economic valuation of nature is not guaranteed to end unsustainable practices, either because immediate payoffs are too great or because the valuation is incomplete and/or contentious. The implementation of NBS infers short-term costs (e.g., management, subsidies and loss of income from resource extraction), whilst benefits are felt long-term (in some cases, not for generations). Legislation mandating net benefit to natural capital ensures a long-term safeguard, and leads naturally to a system where the actor responsible for any erosion of natural capital has to fully mitigate this erosion (the 'polluter pays' principle[267]) and financial incentives that negatively impact nature are removed. For instance, European consumption underlies around 10% of global deforestation[268]. To ensure that erosion of natural capital is not simply transferred from one country to another (offshored) , international legislation for nature-positive production needs to support sustainable corporate governance. A sustainable future requires nature-positive legislation that brings about transparent supply chains without hidden emissions, enabling the 'polluter pays' principle and thereby comprehensive pricing of natural resources.

Democratic and fair implementation

Fair and democratic implementation of environmental policies is key for long-term engagement with citizens[244]. An anticipated target of the Post-2020 Global Biodiversity Framework (Box 2) is for 30% of land and seas to be designated as formal protected areas (PAs) by 2030 ('30x30')[269]. However, implementation of this target without considering the societal dimension could elicit serious human rights abuse and spark local conflicts[270,271] that undermine other SDGs; based on an analysis of likely locations for PA-expansion[272], '30x30' could evict 300 million mostly poor and marginalised people from their lands[273,274]. Conversely, the target could degenerate into a box-ticking exercise where PA expansion ignores biodiversity and/or carbon, and instead focuses on 'convenient' sparsely populated locations without lucrative resource extraction, and where monitoring and realised protection is challenging[275]. The trade-off between PAs with low biodiversity value and, at worst, mass displacement highlights that both people and nature must be central to environmental policies by embracing the notion that productivity and sustainability can work hand in hand.

Recognising local contexts and regional differences

Some trade-offs are almost always necessary to make space for nature. Accurate and fair evaluation of trade-offs necessitate that biodiversity's many facets are recognised at the same time as climate mitigation/adaptation, and peoples through a thorough understanding of local contexts[266,276]. Some positive change is underway, including freeing up land for nature through both rural to urban migration and increased crop yields; however, most necessary change come with costs. For instance, there is no globally universal pathway towards nature-positive consumption because consumption activity is influenced by social, cultural, demographic, economic and political factors[277,278]. Western agricultural systems consider the costs of plant-based diet-shifts greater than stakeholders in predominantly vegetarian countries like India. Successful and lasting changes must therefore be well-informed and weigh heterogenous stakeholder views against environmental facets' various benefits and costs.

Moreover, international frameworks should recognise nations' capacities and limitations, whilst ensuring that local costs with global benefits are justly shared. As an example, since most urban expansion is projected to take place in economically developing regions[279], supportive policies should ensure that the global community help pay for sustainable local solutions with global benefits.

Legislate for change and uncertainty

Biodiversity policies must accommodate various socioeconomic future scenarios, climate projections[45], and how other anthropogenic drivers may change[16,24,280,281]. An example is the anticipated '30x30' target. With accelerating climate change, biodiversity within static PA borders may soon disperse or face extinction[282,283]. Instead, newly established PAs could include sites that, even if not priorities in terms of biodiversity today, are expected to gain natural capital under future scenarios. Policies must take social and environmental projections into account and explicitly build resilience against plausible future scenarios.

Address critical knowledge gaps

Scientists flagged the potential detrimental effects of climate change on biodiversity in the 1970s[284] but, despite rapidly growing understandings of their interactive effects[117] (see the 'Biodiversity and Climate Change' section above), many knowledge gaps remain. Some of the most critical gaps concern biodiversity responses to climate variability and extreme climatic events (as opposed to long-term mean trends), tipping-points and the potential for sudden drastic changes, as well as the interactive effects of climate change and other pressures[257,285,286]. Moreover, understanding of climate-biodiversity interactions must expand beyond well-studied terrestrial ecosystems to include other globally important ecosystems such as belowground soil microbiomes[287] and Earth's most extensive habitat, benthic (seafloor) ecosystems[288].

Adaptive management based on modelling and monitoring

Managing ecosystems to sustainably meet humanity's needs will require a much closer integration between the modelling and monitoring of biodiversity than is currently widespread[289]. Figure 4 outlines how this integration can enable environmental goals to be reached efficiently. First, in the left-hand side of the figure, proposed action targets are assessed in terms of whether, given the understanding embodied in biodiversity models, they are forecast to bring about the desired outcome goal; plans are adjusted until this criterion is met. In the right-hand side of the figure, the ensuing action is accompanied by monitoring of both biodiversity and drivers, to test whether the trajectories are as predicted and to, crucially, enable course corrections.

To maximise its usefulness, these monitoring data should not be private but should instead flow seamlessly into global open repositories of ready-to-use data (as climate data already do), which will therefore have to be much better resourced than at present (as climate data repositories already are) and supported by stronger incentives for open sharing of data. High-quality time-series (of drivers as well as biodiversity) are currently a limiting resource in understanding biodiversity change[155,156,290]; data assembled through this modelling/monitoring framework will help future models to overcome limitations of current ones[289]. Rather than wait until models are perfected before using them – we cannot afford to wait – they will have to be improved through ongoing use-and-test.

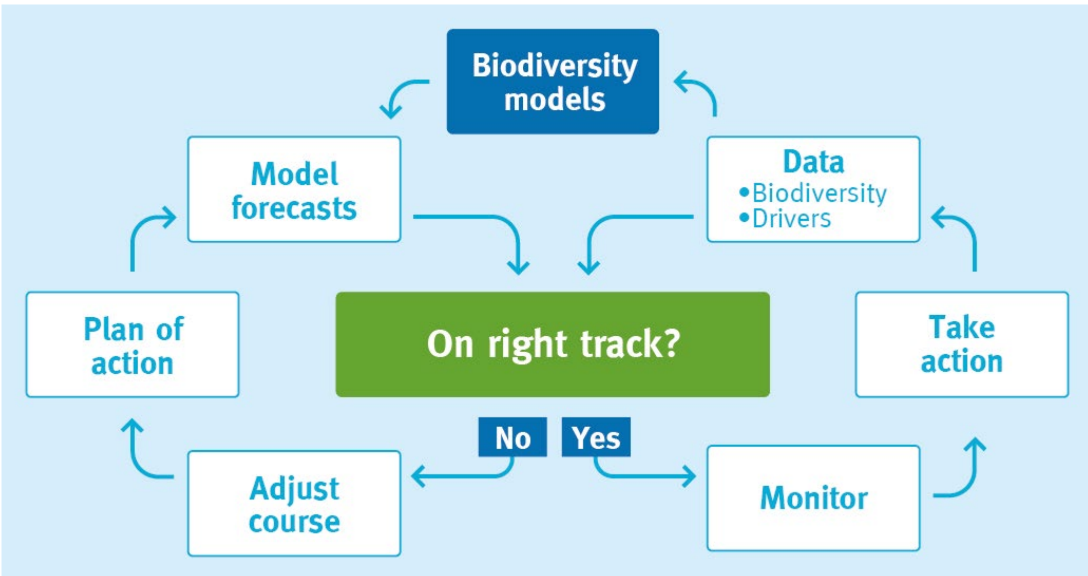

Figure 4: Integrating models and monitoring to reach biodiversity targets efficiently.

Use nature as a living laboratory

Flexibility and innovation are key for science, stakeholders, and practitioners to co-design effective environmental recovery policies through reducing uncertainty and accepting that some change is inevitable. Both climate change and biodiversity loss are projected to initially worsen even under the most optimistic future scenarios[2,291], and incomplete understanding of, for example, tipping points introduces much uncertainty (see the section on 'Modelling and projecting biodiversity climate change interactions'). Given the seriousness of the current situation, the unprecedented challenges it presents, and the urgency for transformative change, where existing policies cannot be relaxed to generate natural capital through protection (e.g., on private land), policies should encourage 'living laboratories' where combinations of intensities of human development and NBS are tested to explore trade-offs and synergies.

Governments could incentivise trials of various proposed environmental interventions, although these may not fall under current environmental legislation. As an example, UK farmers and scientists recently launched a co-designed 12-year trial determining the viability of maintaining agricultural productivity with increasing farmland tree coverage (land-sharing) and associated benefits to climate and biodiversity[292]. However, such long-term trials must run in parallel, not sequentially. Large-scale trials using the landscape as a living laboratory can, within the necessary timeframe, help to design new policy instruments 'bottom-up' with nature, the climate, and people at the centre.

Conclusions

Climate change and biodiversity loss are inherently interconnected twin crises. Not only does climate change impact on global biodiversity; rapid ecosystem degradation, local extinctions and reduced species abundances all deepen the climate crisis. The potential consequences for society are wide-ranging and severe. Although many solutions benefitting biodiversity can significantly contribute to climate mitigation and adaptation, the two are often governed by separate policy instruments both nationally and intergovernmentally. An integrated approach is necessary to realise the full potential of biodiversity to support climate action, as well as to identify, prioritise and implement solutions that deliver benefits on multiple fronts simultaneously.

Creating a sustainable future where people and the planet can thrive will require large-scale restoration of degraded ecosystems, protection of existing habitats and reduction of demand for natural resources. This in turn points to the need for transforming global economic and political structures and societal norms, including subsidies and international trade regulations. However, just as nature must be central to transformative sustainable changes, so must people; otherwise, the already poor and vulnerable risk paying the price for environmental progress.

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