Research paper

# Safeguarding our future by protecting biodiversity

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## ARTICLE INFO

## ABSTRACT

The Anthropocene is marked by twin crises: climate change and biodiversity loss. Climate change has tended to dominate the headlines, reflecting, in part, the greater complexity of the biodiversity crisis. Biodiversity itself is a difficult concept. Land plants dominate the global biomass and terrestrial arthropods probably dominate in terms of numbers of species, but most of the Tree of Life consists of single-celled eukaryotes, bacteria, and archaea. Wild plants provide a huge variety of products and services to people, ranging from those that are species-specific, such as food, medicine, and genetic resources, to many which are partly interchangeable, such as timber and forage for domestic animals, and others which depend on the whole community, but not on individual species, such as regulation of water supply and carbon sequestration. The use of information from remote sensing has encouraged a simplified view of the values of nature's contributions to people, but this does not match the way most people value nature. We can currently estimate the proportion of species threatened by human impacts only for a few well-assessed groups, for which it ranges from 14% (birds) to 63% (cycads). Less than 8% of land plants have been assessed, but it has been estimated that 30—44% are threatened, although there are still few (0.2%) well-documented extinctions. Priorities for improving protection of biodiversity include: improving the inventory, with surveys focused on geographical areas and taxonomic groups which are under-collected; expanding the protected area system and its representativeness; controlling overexploitation; managing invasive species; conserving threatened species *ex situ*; restoring degraded ecosystems; and controlling climate change. The Convention on Biological Diversity (CBD) COP15 and the United Nations Framework Convention on Climate Change (UNFCCC) COP26 meetings, both postponed to 2021, will provide an opportunity to address both crises, but success will require high ambition from all participants.

## 1. Introduction

The preamble to the 1992 Convention on Biological Diversity (CBD) affirms that 'that the conservation of biological diversity is a common concern of humankind' and it would be hard to find anyone who disagrees with this statement. Yet we continue to lose biodiversity, locally, regionally, and globally. What is going on? Why is this still happening when apparently nobody wants it to? One possible contributing factor is that the status of biodiversity as a universal 'good thing' has meant that we have not had to think out clearly what exactly we mean by the term, why we need it, what we ourselves lose when biodiversity declines, and—perhaps most importantly—what we are prepared to do to protect it. Contrast the ongoing biodiversity crisis with the climate crisis, where these questions are readily answerable—indeed, quantifiable—and it is easy to see why it is climate change that tends to dominate the headlines and public attention. The aim of this review, therefore, is first to clarify the meaning of the term biodiversity and then to summarize the links between biodiversity and human wellbeing, with a focus on plants, and to assess the major gaps in our current efforts to protect it.

After the Introduction, I first address the question 'What is biodiversity?' (section 2.), then 'Why protect biodiversity?' (section 3.), 'How many species are threatened?' (section 4.), and 'How can we improve protection for biodiversity?' (section 5.). Finally, I cover 'The twin crises of the Anthropocene: biodiversity loss and climate change' (section 6.) and 'COP15 and COP26: what needs to happen?' (section 7.).

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## 2. What is biodiversity?

For the purposes of the CBD, biodiversity is '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.' In practice, when we think of biodiversity we are usually thinking of the multicellular plants, animals, and fungi that we see around us. Most of the Tree of Life, however, consists of single-celled eukaryotes ('protists'), and bacteria and archaea ('prokaryotes') (Burki et al., 2020).

In terms of global biomass, land plants dominate, accounting for about 80% of the total, followed by bacteria (c. 15%), with fungi, archaea, protists, and animals, in that order, making up the remainder (Bar-On et al., 2018). Plants do less well in all other measures of success, however. In terms of numbers of individuals, viruses dominate (c. $10^{31}$), if they are considered to be alive, followed by bacteria ($10^{30}$), archaea ($10^{29}$), fungi ($10^{27}$), protists ($10^{27}$), and animals ($10^{21}$—mostly nematodes) (Bar-On et al., 2018). The only published estimate for land plants is for trees (3 trillion; Crowther et al., 2015). Note that many of these numbers are subject to considerable uncertainties.

Numbers of species—the most widely used metric for biodiversity—are even less certain, but mid-range estimates suggest that animals do much better using this metric, with recent estimates for terrestrial arthropods of around 7 million species (Stork, 2018), to which can be added a million or so marine arthropods and all the other animals. Fungi are next in terms of species richness, with an estimated 2.2—3.8 million species (Hawksworth and Lücking, 2017). Perhaps surprisingly, a recent estimate for prokaryotes, based on molecular sequence data, suggests a global total of 'only' 0.8—1.6 million of what could be termed species, with this low total reflecting the fact that most prokaryotes seem to be globally distributed (Louca et al., 2019). There are still no robust estimates for the single-celled eukaryotes, while land plants include around 400,000 known species (Nic Lughadha et al., 2016), with perhaps another 50,000—100,000 still unknown (Corlett, 2016).

All these numbers are based, more or less closely, on actual counts, but much higher estimates of species richness for some groups have been obtained by less direct methods. Larsen et al. (2017) estimate that there are six morphologically cryptic arthropod species per described species, giving a baseline number of 40.8 million, and then assume that each of these arthropod species supports, on average, at least one associated mite species (another 40.8 m), and then that each of this new total of 81.6 million arthropods supports at least one nematode, giving a total of 163 million, which dwarfs estimates for all other animal taxa. They then add in associated protists, fungi, and bacteria, giving a final estimate of 1—6 billion species on Earth. They exclude viruses, so their final total is dominated by bacteria, with fungi, protists, and animals accounting for most of the rest. This estimate, and an even higher one (c. 1 trillion species) based on scaling laws (Locey and Lennon, 2016), depend on debatable assumptions and raise the obvious question of how we have failed to detect this additional diversity with the array of methods now available.

However, it would also be a mistake to assume that large numbers of species could not have been overlooked. For example, the diplonemids are a group of heterotrophic marine protists (in the Euglenozoa) which were unknown until 2001 and have since been shown to be diverse and abundant in multiple oceanic niches, making them the most species-rich (>45,000 molecular Operational Taxonomic Units (OTUs)) of currently known marine eukaryotes (Tashyreva et al., 2018). Indeed, whole ecosystems were overlooked until recently. The unexpected discovery of the unique ecosystems associated with hydrothermal vents in 1977 transformed our ideas of where and how life can thrive (Thaler and Amon, 2019), and the gradual unveiling of the deep biosphere—the microbes that exist deep below the land surface and the sea floor—continues to cause surprises. Life—mostly bacteria and archaea, but also some eukaryotes—is found in borehole samples to depths of <5 km below the continents (Magnabosco et al., 2018) and the total global biomass of deep subsurface microbes may exceed that of any other ecosystem except forests.

A phylogenetic perspective on global biodiversity gives a different picture again, with the animals, fungi, and land plants contributing only a couple of fairly minor branches to a eukaryote tree dominated by at least eight predominantly unicellular 'supergroups' (Burki et al., 2020), and the eukaryotes, in turn, probably branching within the archaea (Hug et al., 2016). Most of life's evolutionary history is contained within the bacteria, and most of this diversity is found in lineages known only from genomic data and lacking any isolated representative. Finally, although functional diversity—the range of things that organisms do—is difficult to compare across such different groups, it is clearly low in land plants, which mostly do more or less the same thing, and is exceptionally high in some protist groups.

In summary, we live on a planet that is plant-dominated in terms of biomass, bacteria-dominated in terms of numbers and phylogenetic diversity, and, on current data, probably animal-dominated in terms of species.

## 3. Why protect biodiversity?

Whether there are fewer than 10 million or more than a trillion species, an obvious question is: do we need them all? It is easy to imagine a small group of humans, using near-future technology, surviving indefinitely without biodiversity—perhaps on a space station or a trip to Mars. Food, fiber, and other products could be synthesized from inorganic materials, although it is not clear if humans can function if stripped of their microbiome. Scaling this up to a dirty planet with 7—10 billion people, however, is not imaginable. We would at least need the 250 or so domesticated species that currently supply the bulk of our food and plant-based raw materials (Smýkal et al., 2018).

Do we need wild species as well as domesticates? Wild species are most obviously of value to us when they provide products for human use: so-called provisioning services. For plants, these products include foods, medicines, raw materials (timber, fibers, resins etc.), and energy, as well as genetic resources for plant breeding and biotechnological applications (Corlett, 2018). Timber and wood products are the most valuable products from wild plants in the international trade, but firewood is at least as important locally. Moreover, most domesticated animals feed on wild plant species. More plant species are traded regionally (bamboos, rattans, some traditional medicines), and many more harvested and used locally (wild foods, traditional medicines, minor raw materials etc.).

Some of these uses, such as firewood and forage for domesticated animals, are relatively unselective, although certain species are preferred. For some other uses, such as many timber products, species are usually partly interchangeable. However, use as a wild-harvested food or medicine tends to be species-specific. At least a third of China's flora is used in traditional medicine by one or more ethnic groups (Jaiswal et al., 2016) and at least 22% of Thailand's flora (Phumthum et al., 2018). The collection of wild species also provides an important economic safety net for many poor households and the consumption of wild foods contributes to health by supplying micronutrients lacking in agricultural staples (Rowland et al., 2017). Note that there will often be trade-offs between provisioning services, which involve harvesting wild species, and other

services, including regulating, cultural, and supporting services, which depend on more-or-less intact ecosystems.

The use of wild species as genetic resources does not fit well under 'provisioning', since only genetic material is incorporated into the product that is eventually used or consumed. Wild relatives of crop plants provide an essential resource for plant breeding, allowing on-going improvements in stress tolerance, pest and disease resistance, and nutritional value (Castañeda-Álvarez et al., 2016; Smýkal et al., 2018). Moreover, new genetic technologies are facilitating the use of more distantly related species in crop improvement and highly resolved phylogenies are making it easier to choose the species most likely to be useful for this. The potential uses of wild species in biotechnology, genomics, and synthetic biology are impossible to predict, but this potential means that species with no current species-specific use could acquire new value in the future.

Wild plant communities also provide critical regulating services for people, including regulation of water supply and quality, reduction in flood risk, protection of coastlines, prevention of erosion, protection against dust and sand storms, reduction of air and water pollution, and the regulation of local and global climates (Corlett, 2018). Sequestration of carbon in vegetation and soils offsets some of the carbon dioxide emissions from burning fossil fuels (Houghton, 2020), but vegetation also has immediate impacts on local climates through other mechanisms, including changes in evapotranspiration, albedo, and surface roughness (Li et al., 2020). Regulating services are relatively easy to quantify, but there is usually no simple relationship between plant diversity and the services provided, with monocultures of suitable species serving a similar role. Where a positive relationship between diversity and an ecological function has been demonstrated, or is expected on theoretical grounds, the relationship usually appears to be asymptotic, so only a small proportion of the species present in diverse communities is needed for maximum service provision (Slade et al., 2019). Diversity may be more important when multiple functions and services are considered together, however, since different species will make different contributions to each service. Also, high plant diversity favors high animal diversity, which can, in turn, increase services, such as pollination and recreational bird watching, which depend on this.

Most of the other services provided by wild plants can be loosely grouped under 'cultural services', which include a variety of non-material benefits, from recreation and tourism to aesthetic and spiritual values (Corlett, 2018). Natural and semi-natural landscapes attract tourists, inspire artists, and act as a source of cultural identity for the people who live in them. The religious values of trees and forests are evident in their preservation as sacred sites in numerous cultures across Asia and Africa (Verschuuren and Furuta, 2016). As with regulating services, there is typically no simple relationship between cultural services and biodiversity. In the USA, casual visitors to parks preferred to see an abundance of flowers rather a diversity of them (Graves et al., 2017). However, planted monocultures provide few, if any, cultural benefits.

We do not know what proportion of the 400,000 known species of land plants currently provide species-specific benefits to people, but it is reasonable to conclude that most of them do not. Many additional species are important, but potentially substitutable, sources of timber, firewood, or forage. Moreover, all species contribute to primary production, nutrient cycling, and the provision of habitat, food, and other requirements of animals, fungi, and other organisms. Rare species contribute less to these so-called 'supporting services', but there is evidence that they have the most distinctive traits and thus contribute disproportionately to the potential range of functions in a community (Mouillot et al., 2013; Leitão et al., 2016). Rare species may thereby provide insurance

against future environmental change, including climate change, increasing long-term ecosystem resilience (Dee et al., 2019).

The availability of information from remote sensing, and from regional and global databases, has allowed a subset of ecosystem services—or plausible proxies for them— to be mapped regionally and globally (Ouyang et al., 2016; Chaplin-Kramer et al., 2019). This can be a very useful exercise, but to suggest that this subset of map-able services can represent nature's many contributions to human welfare is misleading. Recent research has emphasized both the importance of understanding the motivations and values that influence public attitudes towards environmental issues, including conservation, and the evidence that people can and do attribute multiple values to the same thing (Arías-Arévalo et al., 2017). Moreover, these multiple values cannot be reduced to a single dimension, however convenient this might be for analysis. It is sometimes suggested that unless values can be expressed in dollar terms, and thus compared with the economic benefits that would flow from an environmentally damaging development, they will be ignored. But if they just don't fit (e.g. spiritual values) or can only be made to fit by grotesque oversimplification (e.g. aesthetic values), such a comparison is meaningless and, indeed, potentially harmful.

A focus on monetary valuation of nature's contributions necessarily emphasizes instrumental values (i.e. the values of wild species and ecosystems as means to an end). This ignores both intrinsic values (the values of wild species and ecosystems as ends in themselves, irrespective of their utility to humans) and relational values (the values derived from interacting with nature in a responsible way), although these non-instrumental values of nature are probably recognized by everyone (Arías-Arévalo et al., 2017). They cannot be monetarized or commodified, and they cannot be bought, sold, or exchanged, but that does not make them any less real.

Despite the limitations of assigning monetary values to ecosystem services, however, natural capital accounting can be a useful complement to traditional financial accounting. Forestry England, for example, produces annual accounts which attempt to summarize all the benefits their forests provide, including carbon sequestration and recreational use whose values greatly exceed those of timber production (Forestry England, 2019). Several known benefits, including flood mitigation and reduction of air pollution, are not yet included in the accounts because they cannot be quantified and given a monetary value, so the estimate of total value is incomplete, but it is still a useful guide for management if the limitations are understood.

## 4. How many species are threatened?

Even for multicellular plants and animals, global Red List assessments are near complete for only a few groups. Estimates for the proportion of threatened species in these groups are 63% of cycads, 41% of amphibians, 34% of conifers, 33% of reef-building corals, 25% of mammals, and 14% of birds (IUCN, 2020). Other than corals, too few invertebrates have been assessed to estimate a global figure for any major group, although some groups, such as land snails (Régnier et al., 2015) and freshwater bivalves (Lopez-Lima et al., 2018), have large numbers of threatened species. On the other hand, if it is true that most microbes are globally distributed, then they will certainly be less vulnerable to extinction than multicellular species with more restricted ranges.

Less than 8% of land plants have been assessed, but estimates based on regional assessments and other sources suggest that 30–44% of assessed species are threatened (Bachman et al., 2018). Threatened species are much more likely to be assessed, but an indirect approach based on a large database of validated occurrence records estimated that a third of Africa's flora is 'potentially or likely

threatened' (Stévart et al., 2019). On the other hand, the number of well-documented plant extinctions is still very low: only 0.2% globally since 1750 (Humphreys et al., 2019) and 0.15% in the well-documented Australian flora (Silcock et al., 2019). This discrepancy could reflect the difficulties of finding rare plants and/or a very long extinction lag time, leading to a large extinction debt.

## 5. How can we improve protection for biodiversity?

### 5.1. Improve the inventory

To protect biodiversity, we need to know which species are where. Around two million species have been described, out of a total likely to be at least 10 million, so doing this comprehensively is clearly impossible at present. The large number of species still waiting to be described is known as the 'Linnean shortfall', after Carl Linnaeus, the father of modern taxonomy. In practice, therefore, conservation operates on the assumption that the biodiversity we know best—usually plants, birds, and mammals—can act as an indicator and 'umbrella' for the protection of everything else: including most insects, nematodes, protists, archaea, and never-isolated bacteria. We do not know how accurate this assumption is, but it is currently the best we can do. Increasing the rate of species discovery and description is therefore a key need for the improving the protection of biodiversity. Birds and mammals are well-described globally, but there are still significant gaps for vascular plants in some parts of the world (such as Myanmar), and much larger gaps for almost all invertebrate groups. Moreover, many new and existing species are described from a single location and sometimes a single specimen (Deng et al., 2019). Such point records are little use for conservation planning, for which we need information on species distributions so that we can assess conservation needs and priorities. This so-called 'Wallacean shortfall', named after Alfred Wallace, the father of modern zoogeography, applies even to the best-known groups taxonomically, although the data for birds is pretty good.

New technologies can help with both the Linnean and Wallacean shortfalls, but 'boots on the ground' are also essential, and the trained people and resources for this will often be the limiting step. Survey effort therefore needs to be focused on the geographical areas and taxonomic groups that are underrepresented in current collections and literature. Molecular techniques can help with identification and, in some situations, surveys (Ruppert et al., 2019; Leempoel et al., 2020). However, arguing for legal protection of a new site because it 'ranks in the top 10% of those surveyed in the diversity of molecular OTUs' will be a lot less effective than providing a list of named species that will be saved! The availability of global environmental data at high resolution from satellites and ground stations enables the extrapolation of sparse point records of a species through modeling to predictions for its entire distribution (Jetz et al., 2019). Citizen science is another increasingly important source of information for filling survey gaps for more charismatic and easily identified taxa (Girardello et al., 2019; La Sorte and Somveille, 2020), in addition to its important role in public education and building support for nature.

Finally, biodiversity data is only useful if it is accessible when and where it is needed, preferably on-line. Approximate range maps are now available for >92,500 species in the IUCN Red List of Threatened Taxa, but these are comprehensive only for terrestrial vertebrates (except reptiles) and a few smaller groups. GBIF (Global Biodiversity Information Facility; www.gbif.org) has more than a billion occurrence records for > 1.7 million species, but data quality and coverage vary greatly between groups and the quality can be difficult to check. The BIEN (Botanical Information and Ecology Network) database has > 200 million plant species occurrence records (Enquist et al., 2019). However, vast amounts of data held in the form of the estimated 2.5—3 billion specimens in natural history collections (museums, herbaria, etc.) remains undigitized and inaccessible without a physical visit to the collection (Hedrick et al., 2020). This can be particularly problematic for tropical countries, where most of the relevant local collections may be held in museums and herbaria in Europe. A priority in these cases should be the digital repatriation of these collections to their countries of origin, as 'virtual museums'.

### 5.2. Protect areas

Protected areas are the backbone of global biodiversity conservation. They function by separating conservation from incompatible land uses, such as agriculture, and excluding other damaging human activities, such as logging and hunting. In 2010, the Convention on Biological Diversity (CBD) established an area target (Aichi target 11) of 17% of terrestrial land and inland water areas protected by 2020. The terrestrial part of this target will be met on a global scale in crude area terms, but Aichi target 11 also calls for the areas protected to be ecologically representative, of high quality, and well-connected, and none of these will be fully achieved in most countries. This target includes not only traditional protected areas, where conservation is the main role, but also 'other effective area-based conservation measures' (OECMs). OECMs are areas with long-term management that are effective in conservation even though this is not their primary role. Examples include protected watersheds and grasslands managed for sustainable grazing. OECMs considerably extend the effective area of current protection and are likely to play a larger role in future if the target area is increased in 2021.

Many of the largest, best-known, and most effective existing terrestrial protected areas were established in regions that were sparsely inhabited at the time, or by colonial administrations that were willing to ignore the traditional rights of local people to use the area. Major expansions of national protected area systems is becoming increasingly difficult because of both the decline in available near-intact habitat (Tuanmu and Jetz, 2014) and the increasing recognition of the importance of social equity in the establishment of protected areas (Zafra-Calvo et al., 2019). In many areas, expansion is only possible if degraded sites—hunted, logged, subjected to shifting cultivation—are incorporated and then allowed to recover, or actively restored. Suggested global protected area targets of 30% by 2030 and 50% by 2050 (Baillie and Zhang, 2018), will be attainable only if the concept of protected areas is considerably broadened, as implied in the CBD's concept of 'other effective area-based conservation measures' (OECMs). At least a billion people live in areas that would be protected if the 'half Earth' idea was applied across all ecoregions (Schleicher et al., 2019).

### 5.3. Control overexploitation

Before the origin of agriculture, people depended entirely on wild natural resources for survival. This was only possible with low population densities, however, and even then resulted in the global elimination of most of the exploitation-sensitive megafauna (Haynes, 2018). The increased densities resulting from agriculture and urbanization, and the associated trade, have subsequently resulted in the serial overexploitation and local extirpation of many animal and plant species, and these pressures are still increasing in many parts of the world. Hunting, logging, firewood collection, and the grazing of livestock are the most widespread impacts, but numerous other species are exploited—and often over-exploited—locally, for food, medicine, pets, ornaments, and assorted raw materials (Corlett, 2018). In theory, most of these

species could be exploited sustainably, but in practice outright bans are usually more easily enforced. Controls on international trade through the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) have been effective in some cases, but for many species the domestic trade is larger so CITES is ineffective. Public education and 'social marketing' can also help but are probably most useful when majority public opinion has already changed.

### 5.4. Protect biodiversity in the human-dominated landscape

Farmlands already cover nearly half of the Earth's vegetated surface and the production of food and other agricultural commodities will need to increase by more than 50% by 2050 (Searchinger et al., 2019). Agriculture is the main driver of biodiversity loss, so it is essential that this expansion in production is achieved in a way that minimizes adverse impacts. Production can be increased by some combination of cropland expansion and agricultural intensification (Zabel et al., 2019). Most evidence suggests that intensification of existing agriculture is less harmful for biodiversity than clearing additional natural habitats, because even low-intensity agriculture supports fewer species than natural areas. However, this may not be true in long-settled regions with a fine-scale mosaic of cultivated and semi-natural areas, and no large areas of intact natural habitat. Similar arguments apply to the much more severe impacts of expanding urban populations, with densification reducing urban habitat quality for wild species but sparing the natural habitats that are threatened by urban sprawl.

Even if 'land sparing' is the best general strategy for conservation in both farmlands and urban areas, as long as human populations and per capita consumption continue to increase, this does not mean that attempts to make agricultural and urban environments more biodiversity friendly are not worthwhile. In most of the world, protected areas are not large and representative enough to protect all species, and 'land sharing', where people and wildlife coexist, will be essential. This will be particularly important for species with large home ranges, such as mammalian carnivores and large herbivores, and the presence of such species in human-dominated landscapes creates a potential for conflicts when crops are damaged (e.g. by large herbivores, primates), and livestock and people threatened (e.g. by lions, elephants) (Crespin and Simonetti, 2019).

### 5.5. Carry out Environmental Impact Assessments (EIAs)

EIAs are used in most countries worldwide to assess the potential impacts of proposed projects so that environmental damage can be avoided or reduced. Impacts on biodiversity are considered in most EIAs, although the quality of these assessments varies considerably (Swanepoel et al., 2019). When done well, EIAs can add an additional layer of protection for biodiversity, but at worse they become a bureaucratic form-filling exercise. Improving the biodiversity component of EIAs is partly a matter of good governance, but it also requires both accessible biodiversity information, since EIA timelines rarely allow for basic research, and an informed and concerned public to ensure accountability.

### 5.6. Manage invasive species

Invasive alien species have been a major cause of extinctions on oceanic islands and reduce local biodiversity in many mainland habitats, although they rarely cause mainland extinctions by themselves (Bellard et al., 2016). When an alien species is established in the wild outside its native change it is rarely possible to eliminate it, so control efforts must focus on preventing introduction and establishment. If a species is already established, then some form of ecological triage becomes necessary, with priority given to managing the species which are most harmful. New ideas, new laws, and new technologies will help in specific cases, but the invasive species problem can only get worse and currently looks to be one of the least tractable of conservation issues.

### 5.7. Conserve threatened species ex situ

Conservation *ex situ* (i.e. in captivity) is never the first choice, but it is necessary for species and genetically unique populations which are threatened *in situ* (i.e. in their natural habitat), and desirable, as back-up, for all species and populations which may be threatened in the future. Current efforts with wild plant species are insufficient and, despite some progress, we are still a long way from achieving the 2020 GSPC (Global Strategy for Plant Conservation) target of 75% of threatened plant species conserved *ex situ* (Sharrock et al., 2018). Conventional seed banks, in which plant species with desiccation tolerant (orthodox) seeds are dried and stored at −20 °C, have been the backbone of *ex situ* plant conservation for some time, but their limitations have become increasingly clear in recent years. Not only do an estimated 8% of all plant species, mostly in the humid tropics, have desiccation intolerant (recalcitrant) seeds that die when dried and frozen, but many crop and wild species have seeds with relatively short (i.e. decades, not centuries) life-spans in standard storage conditions (Colville and Pritchard, 2019). Cryopreservation, usually in liquid nitrogen, is an alternative, both to extend the lives of short-lived orthodox seeds and to enable the long-term *ex situ* storage of embryo axes, buds, shoot tips, pollen, and other tissues of species with recalcitrant seeds (Pence et al., 2020). These technologies could and should be used more widely for threatened plant species.

Cryopreservation and the supporting technologies are more expensive than traditional seed banks, but much cheaper than maintaining plants in cultivation. The small sizes of the genetic individuals protected in seed banks and cryopreservation facilities, and the low maintenance costs, mean that it is practical to preserve many individuals from each population, and multiple populations separately, and thus retain a large proportion of the wild genetic diversity. Living collections of growing plants, in contrast, tend to be small, particularly for trees. There is a rather similar situation with animals, although the technologies are more complex, and the current coverage of threatened species is much poorer than with plants. Cryopreservation of sperm, eggs, and embryos is widely used with domesticated animals, but is much less common with wild species, although a number of 'frozen zoos' exist currently (Charlton et al., 2018). Traditional 'captive breeding' has been important largely for charismatic vertebrates, because it is extremely expensive and requires international collaboration between zoos and other facilities. As with living collections in botanical gardens, the limited population sizes in zoos mean that careful management is required to minimize inbreeding and genetic drift.

### 5.8. Protect phylogenetic and functional diversity

Conservation resources (money, space, time, skilled people, public support) are limited, so their allocation needs careful planning. A focus on the number of species protected may not provide adequate protection for functional and phylogenetic diversity if spatial patterns of species, functional, and phylogenetic diversity do not coincide. Current indices of functional diversity are based on measurements of the 'functional traits' of species in the

community—measurable aspects of an organism that can be linked with its ecological role or fitness—and their application in conservation is based on the assumption that species which do not add to the functional diversity of a community are redundant, and thus deserve a lower conservation priority. While this may make sense when the focus is on the loss of particular function, such as pollination or seed dispersal, a general application of functional diversity in conservation would require that the measured traits are adequate proxies for all ecological functions of a species, which is clearly not true. Phylogeny, in contrast, predicts both known and unknown features of organisms which, in turn, correlate with multiple values of biodiversity (Owen et al., 2019). Phylogenetic distinctiveness—the amount of unique evolutionary history—has therefore become a widely accepted criterion for prioritizing conservation effort. The loss of a phylogenetically isolated species represents the loss of an entire branch of the tree of life. The EDGE (Evolutionarily Distinct and Globally Endangered) program of the Zoological Society of London prioritizes species based on the amount of unique evolutionary history each one represents (Gumbs et al., 2018). This is then combined with a global endangerment score derived from the IUCN Red Lists to give an EDGE score for each species. EDGE scores have proved particularly useful for identifying and prioritizing little-known species which had previously been overlooked, but the wider application of this approach is currently limited by the need for a robust species-level phylogeny and a near-complete global Red List assessment.

### 5.9. Restore degraded ecosystems

Small-scale ecological restoration projects—typically a few hectares or less—have been carried out in many different ecosystems worldwide for several decades with varying degrees of success. Restoration projects can provide additional habitat for threatened species while restoring ecosystem services, including carbon sequestration. Recently, however, there have been calls for a huge expansion in ecological restoration, encompassing millions of square kilometers, in order to meet the needs of both biodiversity conservation and climate change mitigation. The CBD's Aichi target 15 called for the 'restoration of at least 15% of degraded ecosystems' by 2020 and a recent study estimated that at least 1.9 million $km^2$ of land in 114 countries will need to be restored to meet the area component of Aichi target 11 (Mappin et al., 2019). A global forest restoration effort, the Bonn Challenge, called for 1.5 million $km^2$ of land to be committed to restoration by 2020 and 3.5 million $km^2$ by 2030. Most countries also include huge reforestation commitments in their 'nationally determined contributions' (NDCs) to meeting the climate change mitigation targets of the Paris agreement. It is not just the vast areas proposed that are challenging, but also the range of ecosystems involved and the potential for trade-offs between the twin motivations of carbon and biodiversity (considered below).

### 5.10. Control pollution

Even the best fences do not keep out air and water pollution from protected areas. Ozone, sulfur dioxide, and particulates are problems for terrestrial ecosystems in some areas, but the greatest concern globally is deposition of reactive nitrogen produced from fossil fuels and intensive agriculture. Increases in nitrogen deposition impact plant communities through direct toxicity, soil acidification, nutrient imbalances, and changes in interspecific competition (Payne et al., 2017). Impacts can occur at low levels and are easily overlooked.

### 5.11. Stop climate change and minimize the impacts on biodiversity

Controlling climate change is too large and complex a topic to cover here in any detail. The window of opportunity for preventing global warming of 1.5 °C is closing but has not yet closed, and we must rapidly reduce greenhouse emissions and maximize natural sinks (IPCC, 2018). We also need to minimize the impacts of climate change on biodiversity, as we have already had 1 °C of global warming, along with increasing temperature and rainfall extremes, and further warming is inevitable under even the most optimistic scenarios. It may be possible to reduce the impacts in the medium term by minimizing other stresses on wild species, but we also need to provide connectivity across environmental gradients, so species can move to more favorable climates. However, the many edaphic specialists—both plants and animals—may be unable to move (Corlett and Tomlinson, 2020) and many other species will not move fast enough to track favorable conditions (Corlett and Westcott, 2013). Assisted migration may be an option for some of these species, but this needs a lot more research.

## 6. The twin crises of the Anthropocene: biodiversity loss and climate change

In May 2019, the Anthropocene Working Group of the International Commission on Stratigraphy voted in favor of treating the Anthropocene as a formal stratigraphic unit, starting in the mid-20th century. This starting date coincides with the 'Great Acceleration' in population growth, industrialization, globalization, and all their consequences (Steffen et al., 2015). Both biodiversity loss and climate change started well before this date, but it was this post-1950 acceleration in the major drivers of both which produced the twin crises we face today. Climate change and biodiversity loss are often treated separately, but they are interconnected in many ways, including sharing multiple drivers (Seddon et al., 2019). We cannot solve one crisis without addressing the other. This interdependence is recognized in the most recent reports of both the IPCC (Intergovernmental Panel on Climate change) and its biodiversity equivalent IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) (IPCC, 2018; IPBES, 2019). In both cases, there are globally agreed targets, set out in the 2010 Aichi targets of the CBD for biodiversity and the 2015 Paris Agreement for climate change. However, many Aichi targets will certainly not be attained by the 2020 deadline and achievement of the Paris targets is looking increasingly challenging.

Nature-based solutions are increasingly advocated as a way of reducing climate change and its adverse impacts while supporting biodiversity and ecosystem services (Seddon et al., 2020). These solutions include the restoration of natural forests, grasslands, and wetlands in order to store carbon and protect biodiversity, as well as urban greening through parks and green roofs. The costs and benefits of these approaches have rarely been rigorously assessed, and there are potential conflicts between carbon and biodiversity if, for example, ancient natural grasslands are planted with exotic tree monocultures (Bond et al., 2019). The potential benefits are large, but there are also substantial risks and trade-offs (Doelman et al., 2020), and it is essential to build-in adequate safeguards to prevent unintended consequences (Veldman et al., 2019). This is another area where research is urgently needed, as well as modeling studies and large-scale field trials.

## 7. COP15 and COP26: what needs to happen?

We are in a critical period for global progress on both biodiversity conservation and climate change mitigation. Currently, positive trends in both arenas, such as the increase in protected

area coverage and the expansion of renewable sources of energy, are being overwhelmed by continuing negative trends, in habitat and species losses, and in global greenhouse gas emissions. We need to turn these negative trends around and 2021 will provide two unique opportunities for doing this. The parties to the Convention on Biodiversity will meet in Kunming, China, for the 15th Conference of Parties (COP15) and the signatories to the Paris Agreement on climate change will meet in Glasgow, U.K., for the 26th Conference of Parties (COP26) of the UN Framework Convention on Climate Change (UNFCCC). Both meetings have been postponed from 2020 because of the coronavirus pandemic and it is essential that momentum is not lost as a consequence.

COP15 must agree on a post-2020 global biodiversity framework to replace the Strategic Plan for Biodiversity (including the Aichi Biodiversity Targets) for the 2011—2020 period, agreed in Nagoya in 2010. The new targets for 2030 need to be clear, ambitious, inspirational, and measurable. A protected area target of 30% by 2030 would be achievable in most countries, with the inclusion of OECMs, but a percentage target risks directing attention away from the need for effective management of high-value sites and will have to be worded very carefully (Visconti et al., 2019). At the species level, the only reasonable goal is zero extinction, which is already the implied or explicit target for conservation in most countries and should be the global target. The development of the IUCN Red List of Ecosystems also makes an ecosystem target possible and, unlike species targets, potentially possible to monitor with remote sensing (Watson et al., 2020).

In preparation for COP26, each country is expected to update and strengthen the commitments to combatting climate change made at the time of the Paris agreement in their 'nationally determined contributions' (NDCs). As recognized at the time, these initial commitments were insufficient to meet the goals agreed in Paris in 2015, so the first revision is extremely important. Each country's revision needs to set it on a path to carbon neutrality—net zero emissions—by 2050, or soon after. Most of the initial NDCs focused on power generation and forests, but net zero emissions will also require massive changes in transport, industry, and agriculture. Non-state actors—cities, businesses, investors—must be part of this, setting targets compatible with national and global goals. International aviation and shipping will have to be included, for the first time.

COP15 and COP26 are not independent events, since the same countries will be involved, and nature-based contributions to climate-change mitigation will feature in both. Both require high ambition if they are to be successful, and both will require leadership from China, as the host country in Kunming and as the largest current contributor to global greenhouse gas emissions in Glasgow. One lesson we have all learned from the COVID-19 pandemic is that nature does better without us. All over the world, there were unprecedented declines in air pollution, while wildlife reappeared in areas from which it had been absent for decades (Corlett et al., 2020). For a few months, we could clearly see some of the damage we have done, and we will continue to do unless we make drastic changes. In 2021, we have an opportunity to set the world on a new course. Let us use it wisely.

## Declaration of Competing Interest

None.

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