# 10 Must Knows from Biodiversity Science 2022

Leibniz Biodiversity

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# It is not because it is difficult that we do not dare, but because we do not dare, it is difficult.

Lucius A. Seneca, Roman philosopher and poet

**“Biodiversity is collapsing. One million species are at risk of extinction. Ecosystems are disappearing before our eyes. Deserts are spreading. Wetlands are being lost. Every year, we lose ten million hectares of forests. Oceans are overfished – and choking with plastic waste. The carbon dioxide they absorb is acidifying the seas. Coral reefs are bleached and dying. Air and water pollution are killing nine million people annually – more than six times the current toll of the pandemic. And with people and livestock encroaching further into animal habitats and disrupting wild spaces, we could see more viruses and other disease-causing agents jump from animals to humans. Let's not forget that 75 per cent of new and emerging human infectious diseases are *zoonotic*.” With these words, UN Secretary-General António Guterres opened his 2020 speech on the state of our planet.[1]**

The recent report by the World Biodiversity Council (IPBES, 2019)[2], the Global Biodiversity Outlook (GBO-5, 2020)[3] and the first joint workshop report by IPBES and the Intergovernmental Panel on Climate Change (IPCC, 2021)[4] underline this assessment and stress that “resolving the twin crises of climate change and biodiversity loss is critical for human well-being.”[5] The recent IPCC report on the consequences of global warming confirms that maintaining and rebuilding healthy ecosystems represents an essential contribution to climate protection, and that climate and human protection must inevitably go hand in hand with biodiversity protection, in order to be able to shape a liveable future.[6]

In the **10 Must Knows from Biodiversity Science (10MustKnows)** the scientists present facts about biodiversity in a well-founded and generally intelligible way. They analyse the complex systems of the earth by highlighting ten key areas, each of which, in turn, is inextricably linked to all the others. And they show ways to stop the continued loss of species diversity and ecosystems, and to promote biodiversity. The underlying aim is to provide policy-makers and society with scientifically validated assessments of the latest knowledge to facilitate improved policy decisions and action at local, regional, national and global levels, in order to conserve the diversity of life – biodiversity.

The highlighted aspects in each of the **10MustKnows** unmistakably reveal the following: With our way of living and doing business, we consume huge amounts of resources, contribute to climate change and prevent global justice. If we continue like this, we will ruin the foundations of our life on this planet. Be it the air we breathe or the clean drinking water we depend on, food or clothing, fuel or building materials, clean seas or medicines – our lives, our health, our nutrition, our well-being are all based on the tremendous diversity of natural resources that nature provides us

The authors are concerned with more than imparting knowledge. They are concerned about change, about political and social action for a healthy planet.

with. This diversity forms the foundation of a good quality of life for all people on this earth.

The authors are concerned with more than simply imparting knowledge. They are concerned about change, about political and social action for a healthy planet. This is what they wish to foster and encourage. They encourage the conservation of biodiversity and the change of whatever threatens it. They encourage to shape our lives within planetary boundaries. They encourage to get behind a transformation process that will lead to a biodiversity-friendly and climate-compatible civilisation. They encourage this because they know it is possible. There are no justified obstacles from a scientific standpoint. We have the knowledge, we have the economic opportunities and the technologies to shape change. Rather, obstacles are structural, social, cultural and political in nature.

The authors invite everyone to participate in a dialogue, because restructuring requires the knowledge of all knowledge cultures and the participation of all. As recommended by IPCC and IPBES, solutions must be developed respectfully with all stakeholders, they must be implemented step by step, and a willing to continue the learning journey must prevail. [5]

A "business as usual" approach would essentially translate into preventing the conservation of biodiversity. The Aichi Biodiversity Targets of the Convention on Biological Diversity (CBD)[7], the Sustainable Development Goals of the United Nations (SDGs)[8] and the targets underpinning both the European[9] and the national biodiversity strategy[10] will be missed without consistent efforts from the political sphere and society as a whole.

The UN Biodiversity Conference this year is about adopting an effective post-2020 biodiversity framework (*Global Biodiversity Framework*, GBF) and implementing it with effective measures. In order to promote informed policy decisions, these **10MustKnows** provide scientifically validated assessments of the latest evidence. They offer specific proposals for solutions to key political problems.

The sources for a justice-oriented biodiversity policy have by no means been conclusively explored, let alone tapped into: Nature, when explored, provides inspiration, guidance and foundations for what is a long overdue and fundamental transformation of our lives in wider society. Let us solve the biodiversity, climate and justice crises and build a life-sustaining civilisation for the entire globe!

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# 1 Achieving climate and biodiversity protection together

1 Because diverse ecosystems are more resilient to climate change and natural forests and peatlands store large amounts of carbon, there are numerous synergies between climate protection and adaptation as well as biodiversity conservation.

2 However, maintaining a one-sided focus on climate protection can also lead to undesirable side-effects on biodiversity, e.g. when large-scale bioenergy plantations displace natural ecosystems.

3 The expansion of protected areas worldwide (30 per cent by 2030, 50 per cent in the long term) would represent an important step towards preserving the functioning of aquatic and terrestrial ecosystems and their biodiversity. If managed properly (> MustKnow7, 8), they make an important contribution to climate regulation and climate protection.

4 Between 25 and 67 per cent of globally utilised land is now used for the production of exported goods. Consumption in other regions thus causes a loss of natural habitats in the producing regions, and increases greenhouse gas emissions there. These biodiversity losses caused by consumption must be taken into account in (national) biodiversity strategies.

5 In order to enable synergy effects for climate and biodiversity protection, biodiversity protection and development must also be anchored, designed and implemented in a more binding fashion in corresponding laws and plans.

## Biodiversity protection also promotes climate protection if losses in nature are stopped, and ecosystems essential to climate regulation are comprehensively protected, sustainably managed and restored.

Functioning marine and terrestrial ecosystems contribute directly to limiting global warming by stabilising $CO_2$ pools important for climate, and maintaining the hydrological cycle. Land-use change and direct resource exploitation on land and water are leading to dangerous climate change, as well as biodiversity loss.[1] The degradation and destruction of natural ecosystems endanger biodiversity and climate alike.[2,3] The Amazon rainforest, previously an important global $CO_2$ sink, is now releasing $CO_2$ due to severe deforestation and climate warming.[4] Biodiversity losses are lower, the more global warming can be limited to below 2°C.[5]

If the continued loss of natural ecosystems is avoided, degraded ecosystems restored, cropland, pastures and managed forests can be used sustainably and crop losses reduced, meaning that climate and biodiversity can be protected equally and most effectively while avoiding trade-offs with other sustainability goals.[2,3]

Many ecosystem-based approaches to climate protection are currently being tested for their feasibility, scalability and socio-ecological consequences. [2,3] Conflicting goals over land use are particularly evident in the area of bioenergy ("fuel vs food"). In order to achieve the Paris climate targets, a massive global

**30–50%**

of land and ocean areas are needed to stem marine, aquatic and terrestrial biodiversity loss.

Land ecosystems and the ocean have absorbed approx.

**55%**

of anthropogenic $CO_2$ emissions in the last ten years.[27]

The import of beef and soy into the EU destroys

**120,000**

hectares annually of natural ecosystems in the Mercosur countries and increases global warming.

expansion of bioenergy systems with $CO_2$ capture and $CO_2$ sequestration underground is being discussed. This could take up more than half a billion hectares of land.[1] Such a scenario is barely compatible with the goal of halting biodiversity loss, and it also conflicts with the principle of global food security.[1]

Protecting climate and biodiversity effectively means protecting 30 per cent of land and marine areas by 2030 and declaring another 20 per cent as so-called *climate stabilisation areas*, which 67 per cent of terrestrial ecoregions are suitable for.[6] The extinction risk facing tropical species could be halved if the 2-degree target was met and 30 per cent of the land area was protected.[7] If one billion hectares of degraded ecosystems worldwide were restored, this could cover one-third of the mitigation action needed by 2030, while preventing two-thirds of projected species extinctions.[8] Biodiversity loss in marine ecosystems due to climate change could be mitigated if 21 per cent of the ocean (43 per cent of the exclusive economic zones and six per cent of the high seas) were protected.[9] Ecosystems will continue to change even with 1.5°C global warming; a general shift in thinking from a static to a dynamic adaptation approach is required.[3,10,11]

Between 25 and 67 per cent of the world's land area in use, the deforestation caused and greenhouse gas emissions can now be attributed to global trade.[12] The goods imported annually into the EU (mainly beef and soy) destroy 120,000 hectares of natural ecosystems in the Mercosur countries of South America every year.[12] Unabated global demand for natural resources means causing biodiversity loss and regional climate change elsewhere through trade.[12,13]

Biodiversity protection in spatial and landscape planning, in environmental assessments and in *Biodiversity Offset* Mechanisms should, e.g. for EU member states, be more legally binding. This means that the avoidance and mitigation of (and compensation for) instances of impact on biodiversity and global climate must be considered more strictly in land use decisions[14] (> MustKnow7). For example, the protection of biodiversity or the designation of areas for nature conservation and landscape management could be formulated more frequently in regional spatial plans as a goal and not as a principle, so that this concern is given greater legal weight. In addition, biodiversity could be anchored as an urban development goal in a country's Building Code. In addition to the enforcement and stricter control of the no net loss principle, a "net gain requirement" should find its way into the impact regulation and biodiversity offset mechanisms, in order to achieve the new EU target of a "surplus" in biodiversity and ecosystem services.

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The Amazon rainforest, previously an important global $CO_2$ sink, is now releasing $CO_2$ due to severe deforestation and global warming.

**Background**

Globally, less than 30 per cent of forests are considered intact[15], and regionally, degraded areas can even exceed deforested areas (e.g. in parts of the Amazon rainforest[16]). Even today, climate change and the resulting increase in global disturbances and *pathogen* damages are leading to increased forest dieback[17,18] (> MustKnow5) in many places. Preventing deforestation means preventing global emissions of between 0.4 and 5.8 Gt $CO_2$e (*$CO_2$-equivalents*) per year. Protecting forests from further degradation can prevent further emissions of 1 to 2.18 Gt $CO_2$e per year.[2] Protecting and restoring certain marine ecosystems would allow carbon uptake of up to one Gigatonne of $CO_2$e per year.[2]

Many of the approaches to climate and biodiversity protection focus on forests. Further synergy effects can be achieved if sensitive ecosystems are also protected. Long-term restoration of peatlands and their sustainable use ensure their biodiversity, reduce $CO_2$ and methane emissions, protect against droughts and enable the production of renewable raw materials.[19,20] Marine sediments store twice as much carbon as terrestrial soils. But only two per cent of this habitat lies in highly protected areas and is thus protected from disturbances to the seabed.[21] Preserving marine

The deforestation of tropical forests for agricultural land continues  unabated, largely for exports.

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food chains also stabilises ecosystems and their biogeochemical cycles. For example, if the world's whale population were to recover to its original size, its excreta would help recycle marine iron and thus increase marine productivity in the Southern Ocean.[22] Marine ecosystems are threatened in their stability by heat waves in the ocean, continued nutrient input and the use of marine resources.[2,3]

The degradation of tropical forests for agricultural purposes continues unabated, largely for exports. (> MustKnow8) For example, about 20 per cent of soy exports and at least 17 per cent of beef exports imported from Brazil to the EU probably come from illegally deforested areas of the Amazon rainforest and the adjacent Cerrado dryland.[23]

The protection, management and restoration of ecosystems within the framework of *Nature-Based Solutions* are time- and cost-efficient measures that serve both climate protection and biodiversity goals.[24] The implementation of biodiversity-related avoidance, mitigation and compensation measures must be more rigorously reviewed from the standpoints of accountability and monitoring. The initiative by the EU Commission to introduce the instrument of landscape or green space planning throughout Europe[25,26] is particularly worthy of support. With such a new EU-wide planning instrument, the concerns of climate protection, climate change adaptation and biodiversity protection could be coordinated in an ideal way (> MustKnow8).

### Policy recommendations

1. An immediate end to the destruction of natural forests and peatlands would have decisive positive effects on climate and biodiversity protection. Given that outsourced biodiversity losses play an important role, they should be taken into account in national biodiversity strategies.
2. An integrative approach to biodiversity and climate protection should include measures to protect, maintain and develop biodiversity, as well as measures to adapt to climate change and absorb $CO_2$. In line with the EU Biodiversity Strategy 2030, they should be promoted through a budget linked to the landscape or green plan.
3. Conflicting goals and synergies must be taken into account when developing holistic solutions, also in relation to further sustainability goals, e.g. food security.

### Societal recommendations

1. Climate and biodiversity protection are two of the greatest challenges facing our society and must be tackled together.
2. Our consumption in Germany and Europe influences climate, deforestation, habitat destruction and biodiversity globally.
3. We need new and holistic approaches to climate and biodiversity protection, which secure human well-being in the long term. Our strategies will have to continuously adapt to the changing environment.

# 2 Strengthening planetary health

**Human physical, mental and social health is linked to biodiversity through the following four pathways[1]:**

**1** Biodiversity provides food and medicines, regulates our climate, protects against heat and cleans pollutants in water, air and soil.

**2** Biodiversity can restore human health and well-being, e.g. by stress reduction and attention restoration.

**3** Green and blue infrastructures in urban and rural areas, i.e. green spaces and water bodies, render an important contribution to building people's mental and physical health capacities, e.g. by promoting physical activity or transcendental experiences – such as awe and reflection.

**4** Biodiversity also safeguards human health by regulating the dynamics of biological communities, including their pathogens. Protecting and restoring biodiversity, regulating the wildlife trade, and sustainable agricultural practices are effective *primary pandemic prevention* measures that incur only a fraction of the cost of the actual pandemic.[2]

## A healthy planet needs biological diversity: Its protection and restoration represents an investment in ecosystem functioning, which is essential for human health and well-being.

Nutrition provides a fundamental contribution of biodiversity to human well-being and health. A predominantly plant-based diet is beneficial for both human health and biodiversity.[3] Heavily processed and animal-based foods, on the other hand, harbour risk factors for cardiovascular disease and diabetes. In addition, the production of meat directly (grazing land) and indirectly (feed production) occupies large areas of land, affecting or destroying undisturbed ecosystems, promoting species loss and diminishing genetic diversity, including that of pollinators important for food production.[4] Protecting human health requires a balanced diet that leaves a smaller *environmental footprint* while reducing food waste in middle- and high-income countries and ensuring adequate nutrition in low-income countries.[3,5,6] Promoting agroecosystems that ensure pesticide-free and deforestation-free trade chains protects biodiversity and reduces greenhouse gas emissions (> MustKnows5, 6, 7).

Medicines from natural sources also represent an important and direct benefit to human health.[7,8] About 50 per cent of modern medicines are based on natural products.[9] The loss of biodiversity limits the evolutionary potential to continue producing new, therapeutically effective plant species. Species with therapeutic potential could thus disappear before they have been discovered.[10]

In addition, biodiversity provides important health benefits through the regulation of climate, air, water and soil, as well as the reduction of environmental pollution.[11] (> MustKnows3, 5, 6, 7, 10).

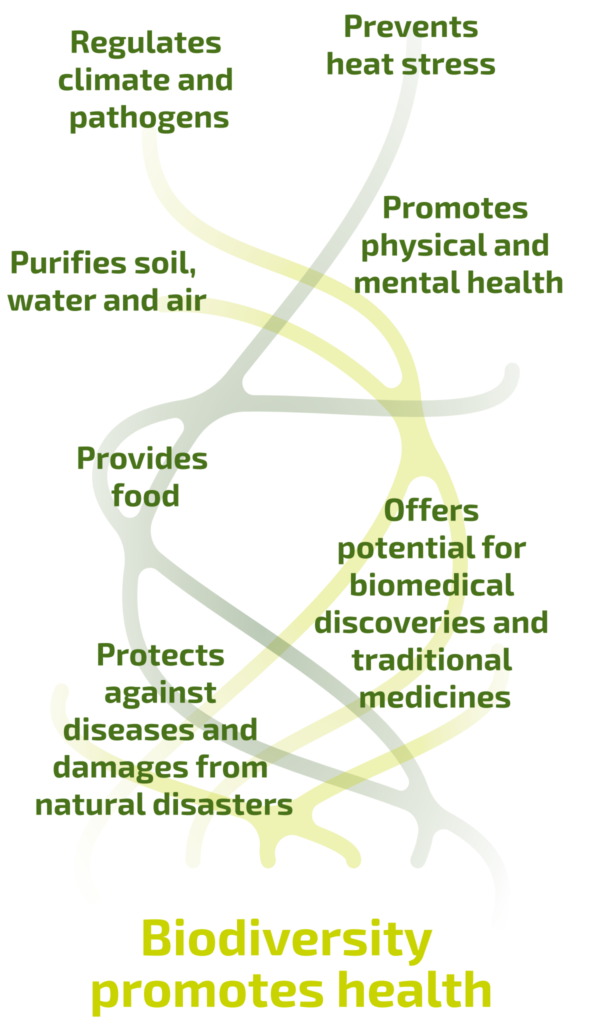
# If the destruction of ecosystems and their respective functions is not slowed down, the global health gains achieved over the past 50 years could be reversed.

Biodiversity can contribute significantly to reducing physiological stress [12], increasing life satisfaction[13] and helping to focus attention.[14] As experienced during Covid 19-related lockdown events, urban green and blue infrastructure (green spaces and water bodies) are also important for recreation and encouraging physical activity – such as walking or outdoor sports.[15] We are, however, witnessing an increasing loss of opportunity to enjoy nature and develop species knowledge[16], which may limit such restorative competencies. Accessible urban green spaces, gardens, street trees and other *nature-based solutions* promote biodiversity, invite people to pursue outdoor recreation, contribute to local cooling, mitigate air pollution and can even serve as (rain) water storage. Across all sectors, these measures support (and help to realise) biodiversity goals, as well as health and climate goals.

Biodiversity stabilises the dynamics of biotic communities, including their *microbiomes* and pathogens. This also includes  us as humans and our societies.. If the delicate balance is disturbed, species that tend to cope well with a variety of environmental conditions and the proximity of humans (e.g. rats) can multiply at the expense of specialised species.[17]*Spillover events*, in which pathogens normally found in animals acquire the ability to infect humans, may thus occur more frequently. Increased opportunities for transmission and changes in the pathogenic genome favour this development. Human interventions that reduce biodiversity and increase the rate of contact between wildlife and humans are also associated with stress on wildlife communities and effects on their immune systems.[18] If their immune systems are weakened, pathogens may be released into the environment in greater numbers. The risk of spillover events thus increases the more humans encroach on the habitats of wild animals, hunt wild animals or trade with them. Mass livestock farming also provides pathogens with an environment in which they can proliferate and mutate to a significant degree. Actions that endanger biodiversity thus also increase the risk of novel infectious diseases emerging.[19-21]

However, the importance of wildlife health for human health and functioning ecosystems has been largely overlooked in global health and biodiversity strategies.[22,23] Wildlife and environmental aspects are also neglected when it comes to health security priorities and plans. A recent study found that more than half (58 per cent) of the 107 reporting countries and territories did not have functioning wildlife health

**Nature conservation and nature-based solutions**
promote ecosystem services that contribute to human, animal and environmental health



While about

**70%**

of agricultural land is used for the production of feed for livestock, only 25 per cent of this area is needed for a plant-based diet.[28]

The estimated cost of primary pandemic prevention over a ten-year period is only about

**2%**

of the estimated costs of the COVID-19 pandemic (as of 2020).[25]

Whoever spends at least

**120**

minutes per week in nature strengthens their own health and sense of well-being.[47]

surveillance programmes as part of their health security planning, including pandemic prevention.[22] These findings are alarming, considering the human-wildlife transmissions of SARS-CoV-2 alone and the potential consequences this could have for mutations, new variants and pandemic containment (e.g. [24] > MustKnow3). Pandemics could be stopped at the source. The costs of primary prevention of s are estimated to account for only roughly two per cent of the costs caused by the COVID-19 pandemic (as of 2020, conservatively estimated ). Just how important the health of wildlife is in relation to human health is also shown by the example of insects and pollinators: Healthy insects and pollinators contribute to soil health, on which food security and dietary diversity depend.[26]

Parallel to the climate crisis (> MustKnow1), the following applies: If the destruction of ecosystems and their respective functions is not slowed down, the global health gains achieved over the past 50 years could be reversed.

However, health could be a unifying value and a lever to communicate the urgency and magnitude of the danger we currently face. Our life support system depends on the web of life being diverse – not only when it concerns keeping pathogens at bay, but also for the sake of nutrition and climate. Biodiversity conservation is a multidimensional strategic advantage, in order to advance global health policies and practices, and to achieve and secure sustainable planetary health.

**Background**

Food production, which focuses on increasing crop yields and maximising livestock production, places significant pressure on biodiversity, e.g. through deforestation, drainage, the use of fertilisers, pesticides, herbicides and nutrients, as well as the production of animal feed.[27] Meat production also forces the production of animal feed, e.g. soybeans, which has a significant impact on biodiversity loss in low- and middle-income countries. While approximately 70 per cent of agricultural land is used to produce feed for livestock, only a fraction is needed for a plant-based diet, which also saves land for nature conservation (> MustKnow7).[28] Health care for 70 to 80 per cent of the world's population is linked to traditional medicines,[29] with more than 30,000 species known and recorded worldwide for their medicinal properties. As reported for the United States, the majority (75 per cent) of all antibacterial, antiviral and antiparasitic drugs come from natural products.[9]

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Species diversity of both birds and plants has been shown to correlate positively with life satisfaction[13] and reflection[30,31]. It was also shown that a higher density of street trees in the immediate vicinity of the home was associated with a lower rate of antidepressant prescriptions.[32] As nature-based solutions, street trees can also contribute to climate change adaptation by, e.g. providing effective local climate and water regulation.[33,34] The rule of thumb – "3-30-300" – provides useful guidance for the provision of urban trees in urban communities (3 trees per house, 30 per cent tree canopy in each neighbourhood, 300 metres from the nearest public park or green space).

There are an estimated 700,000 unknown viruses in wild mammals and birds that could potentially pass to humans.[35] Most human infectious diseases are of animal origin, e. g. influenza, HIV and Ebola, SARS-CoV-2.[36,37]

75 per cent of emerging or novel human pathogens are *zoonotic*.[38,39] Emerging infectious diseases such as the Nipah and Hendra virus outbreaks[40,18] are linked to the loss of wildlife habitat and the deterioration of wildlife health that are associated with increased human, livestock and wildlife contact. Eight of the 15 temperate zone diseases have probably been transmitted to humans by livestock (diphtheria, influenza A, measles, mumps, whooping cough, rotavirus, smallpox, tuberculosis).[41] The recent outbreaks of e.g. MERS, avian flu and swine flu are all based on inappropriate animal husbandry systems.[42]A major threat to human health also stems from the rising rate of antibiotic resistance, with resistant organisms spreading rapidly from the clinic and the livestock farm into the surrounding environment, which can increase the risk of antibiotic-resistant infections.[43,44] The rise of this resistance represents one of the greatest threats to global health[45] and could be mitigated by changing agricultural practices (> MustKnow6).

## Policy recommendations

1. Strengthening area protection and ***ecosystem health*** to secure essential ***ecosystem functions***, such as food and future pharmaceutical discoveries, and to enable primary prevention from future pandemics and proactive virulence management.[2,46]
2. Investing in human health by protecting and restoring biodiversity, e.g. by planting street trees or restoring floodplains. Promotingcross-sectoral collaboration between conservation and public health agencies as proactive public health investments that e.g. mayalso be financed by health authorities.
3. Proactively dovetail veterinary and human health systems while integrating wildlife health, in order to contribute to functioning ecosystems and mitigate zoonotic disease risks.

## Societal recommendations

1. Shift to a sustainable, largely plant-based diet that reduces our ecological footprint and food waste, while also improving our health.
2. Promote nature-based solutions for public health, such as the maintenance and expansion of urban green spaces, as well as the promotion of nature-based activities, e.g. gardening or other recreational activities in nature.
3. Only buy products that are sustainably grown and from wildlife-friendly supply chains.

# 3 Considering hidden biodiversity

1. Ecosystems, communities and organisms that are less visible or accessible to humans tend to be understudied. They require greater attention in conservation planning. Existing conservation efforts often focus on large terrestrial animals and plants.

2. Inland waters are less protected than terrestrial and marine habitats. A decline in excess of 80 per cent of large freshwater vertebrate populations is an urgent call to drive forward biodiversity research and conservation efforts in this area.

3. Microorganisms and microfauna, in particular, play an important role in ecological functions in soils, sediments and aquatic ecosystems. The study of interaction networks (including *mutualistic* symbioses, *holobiont* systems, and host-parasite interactions) is important, in order to better understand the vulnerability and resilience of biodiversity and ecosystems, and to predict outbreaks of emerging diseases and invasions of alien species.

4. The night-time brightening of the hemisphere is increasing in radiance and extent by two to six per cent annually worldwide. It is a new phenomenon with which life on Earth has not yet gained much experience. Significantly more attention should be paid to the physical changes of the night.

5. Evolution can occur rapidly, thereby having an enormous effect on biodiversity responses to global change, the *resilience* of ecosystems and their impact on human well-being. New environmental monitoring tools (testing of wastewater, swabbing of floors in buildings) can serve as an early warning system to detect new variants of *pathogenic* microbes (e.g. the coronavirus).

## Truly comprehensive conservation of biodiversity requires taking into account numerous relevant habitats, organisms and their interactions, which are currently not the subject of sufficient study and examination.

Comprehensive conservation of biodiversity requires more attention for invisible biodiversity, including organisms that are active when we sleep, that live in the water or in the soil, or that the human eye cannot perceive. The 2019 report summary for policymakers by the World Biodiversity Council (IPBES), Annex 4, identifies knowledge gaps. The table names biotic communities in biomes that exist primarily below the surface. These include freshwater, Arctic, marine/ocean, seabed, and wetlands. Inventories in soil, benthic and freshwater environments, and the implications for ecosystem functions. In the following, we give examples that illustrate the important role invisible biodiversity plays in maintaining ecosystem functions and nature's contributions to people, e.g. for nutrient cycling, *primary production*, soil formation, pollination or habitat creation.

The populations of large freshwater vertebrates have declined by

**84%**

Dam projects can accelerate this process.

Soil biota stores roughly

**92Gt**

$CO_2$ and thus mitigates the greenhouse effect.

Worldwide, the night-time brightness is increasing by

**2-6%**

annually. Artificial light at night is an important driver of global change and should receive more attention.

In nature conservation planning, information on invisible biodiversity should be systematically added to make protected areas more sustainable and ecological.[1] Studies point to the key importance of lateral (such as river banks and floodplains) and vertical (such as surface and groundwater) connectivity in ecosystems.[2] Maintaining biodiversity in lakes, floodplains, small water bodies and free-flowing rivers is an urgent measure needed to prevent further degradation in freshwater ecosystems.[3,4,5] Furthermore, the lack of data pertaining to the risk of extinction and population trends, especially among insects, parasites, fungi and microorganisms, are named as knowledge gaps. However, such data is essential because these ecosystem components play a central role both as recyclers of nutrients and energy, and as sources of novel compounds for biological research.[6] The conservation of soil biodiversity (25 per cent of all species on Earth) is elementary to all above-ground ecosystems and their functions. The study of invisible organisms, e.g. in soils, can be promoted by using modern *molecular high-throughput methods* in combination with bioinformatics and modelling. But, the data must be linked to metadata – such as soil type and use or microclimate – which is today often lacking.[7] Soil organisms play an important role in the connectivity of ecosystems and are particularly affected by anthropogenic impact. Yet, in the planning of protected areas they are subject to relatively little interest. [8]

Artificial light at night is often overlooked as a driver of global change. Nighttime illumination can fragment and disrupt ecosystems, affect natural cycles of light and darkness, alter seasonal and circadian behaviour, and impact a wide range of biological processes: from *gene expression* to ecosystem interactions and *ecosystem services*.[9] However, the effects of artificial light at night as a threat to biodiversity are rarely considered in environmental regulations.[10] A study[11] proposes to strengthen regulations against light pollution in protected areas on a global scale, e.g. in the form of dark infrastructures that preserve relatively natural light conditions in nocturnal habitats (> MustKnow8). This proposal is in particular important to follow the IPBES report's recommendation to safeguard urban key biodiversity areas and ensure that they are not isolated (> MustKnow8).

Networks of interacting species can improve the resilience of ecosystems (*resistance*) to stress factors. The diversity of interactions in holobiontic systems, host-parasite, predator-prey and mutualistic relationships is a critical component of biodiversity in all systems. These networks play out at the level of host individuals (e.g. mutualistic and parasitic networks in the *microbiome* of the host), in habitats (tree crowns or root systems), as well as at the level of entire ecosystems and *meta-ecosystems*. There are many parallels in the spread of emerging pathogens and the spread of *invasive* alien *species*[12] which also have strong impacts on global biodiversity and socio-economic systems.[13] Understudied habitats or biomes are often heavily invaded by non-native species, with little knowledge of their effects on species interactions. It is important to explore interaction networks and monitor the arrival, establishment and spread of high-impact invasive species so that appropriate management measures can be initiated in time.[14]

A growing number of studies indicate that evolutionary dynamics can strongly influence key features important for conservation measures. These include population growth rates, interactions between species and the capacity of organisms to respond to global change. Predicting the responses of organisms and ecosystems to climate change (including urbanisation)[15] requires mechanistic insights that connect dispersal, species interactions, physiology, and evolution.[16] Evolution can also play an important role in buffering environmental change in medium-term[17] and in strengthening the resilience of populations. This can impact the occurrence and dynamics of ecosystem collapse and regime shifts in complex systems.




Therefore, knowledge of evolutionary dynamics is a crucial aspect of biodiversity.[18] Evolutionary processes also have direct impacts on population health and the economy, as the COVID-19 pandemic reminds us.[19] The comprehensive assessment and monitoring of habitats, e.g. in wastewater[20], and the built environment[21] and of otherwise overlooked organisms, may offer new opportunities for biodiversity conservation and for the development of models that can predict the responses of organisms and ecosystems to human-induced environmental change.

**Background**

Studies show that habitats and organisms living below the surface in water, sediments or soils are not considered by environmental protection regulations to the same extent as large, terrestrial animals and plants. In freshwater habitats, vertebrate populations are estimated to have declined by 84 per cent since 1970.[22] To protect freshwater biodiversity, free-flowing water bodies, intact wetlands and large catchments must be maintained or restored.[3] Nevertheless, available habitats for freshwater *megafauna* are severely threatened by planned dam projects. In 19 per cent (94 out of 497) of today's free-flowing rivers that are more than 500 kilometres in length and contain large freshwater animals, fragmentation by future dam projects is likely.[3]

Current knowledge gaps regarding the drivers of soil death are worrying, especially when considering that most above-ground ecosystem services depend to a large extent on the functioning of soil biota.[23] For example, no models for soil organism extinctions are currently available. Population dynamics models lack information on the predictability of asexual reproduction (which is present in many soil organisms) and on resting structures for extensive periods of time. To better understand how soil organisms cope with fluctuating food availability due to global change, future research should merge studies about the balance of nutritional elements and organic matter with evolutionary and classical population and community ecology.[24] This knowledge is crucial because soil biota prevent roughly about 92 Gt $CO_2$ from entering the atmosphere.[25]

Artificial light at night can affect nocturnal organisms, their habitat and their movements – including microorganisms, biotic communities and their interactions – triggering so-called *cascading effects*. These can alter basic *ecosystem functions* such as mineralisation, pollination or seed dispersal.[9] More attention urgently role of light at night as a global change driver. The increase in the intensity and extent of brightness is estimated to be between two and six per cent per year globally.[26] Regulations against light pollution can protect important areas for biodiversity and, at the same time, lower $CO_2$ emissions by reducing energy consumption (> MustKnow1). Furthermore, it is important to understand how increasing night-time brightness and temperature can influence each other in terms of seasonal changes, habitat use and the potential for invasive species.

It is also becoming increasingly clear that knowledge of interaction networks between species is crucial to understanding how ecosystems function, how resilient they are, and how they respond to human-induced stress factors. While *animal pathogens* and parasites can play an important role in maintaining host immunity and genetic diversity, they also pose a major (and increasing) threat to human society. Rapidly reproducing organisms that occur in high numbers such as viruses, bacteria and other microbes are particular susceptible to developing resistance to toxins such as antimicrobials[27] or pesticides[28]. Over the past two decades, outbreaks of *zoonotic* and *vector-borne diseases* have increased dramatically(> MustKnow2). As the current COVID 19 pandemic has shown, the occurrence of zoonotic diseases remains difficult to predict. There is also a lack of knowledge concerning the diversity of organisms relevant to the interplay of ecological health.[29]

## Policy recommendations

1. Protected areas must be planned large enough and contain barrier-free corridors and catchment areas, so that biodiversity can fully develop during the day and at night, both above and below the surface.
2. In order to detect the decline of organisms and habitats that have received less scientific attention and thus to preserve functioning ecosystems, there is a need for connected monitoring and detection systems across a range of natural and built habitats around the globe and an organised, interdisciplinary exchange between science and politics.
3. In order to establish comprehensive ecosystem protection measures and anticipate emerging pathogens or mismanagement that could lead to floods, droughts, soil loss or other destructive forces, the monitoring and assessment of macro- and microorganisms in soil, freshwater and sediments are urgently needed. This knowledge needs to be linked to metadata about the soil or sediment, catchment areas, climate, and land use (including illumination).

## Societal recommendations

1. Manifold ecosystem-relevant interactions are invisble; it is, therefore, important to generally consume as sustainably as possible, in order to conserve nature's resources and avoid the unconscious disturbance of ecosystems.
2. Natural areas such as gardens or parks should be designed to support the connectivity of habitats. Diverse and native plants connect habitats; whereas exotic plants, constructions and poorly planned illumination can create barriers.
3. The global assessment and monitoring of biodiversity and the drivers of its decline, as well as of microbial interactions and the connectivity of ecosystems in soil, freshwater and sediments – both during the day and at night – are needed, in order to halt biodiversity loss.

# 4 Promoting biocultural habitats

1. The concept of biocultural diversity considers the diversity of life in its human-environmental dimensions, including biological, sociocultural, and linguistic diversity. Biodiversity, cultural diversity and linguistic diversity are interconnected and have co-evolved as socio-ecological systems.

2. Indigenous Peoples and Local Communities (IPLCs) play a crucial role in the sustainable use and conservation of biodiversity and ecosystems. Recognizing IPLCs' rights to their territories and resources is fundamental for the maintenance of biodiversity.

3. IPLCs around the world hold diverse worldviews, values, institutions and governance systems that are crucial to maintaining biocultural diversity and sustainability.

4. Sophisticated environmental knowledge systems held by IPLCs are of paramount importance for informing and guiding scientific research, development projects, conservation and environmental policies, and bioeconomy initiatives.

5. Most indigenous/local languages are critically endangered by the same forces that threaten biodiversity. Just as these languages, cultures and worldviews are in danger of extinction, so are the associated knowledge systems that are linked to and sustain biodiversity.

Biological, sociocultural, and linguistic diversity are deeply interconnected, having co-evolved as social-ecological systems, and key to their conservation are the knowledge and practices of indigenous peoples and local communities.

The concept of biocultural diversity considers the diversity of life in its human-environment dimensions, including biological, human, cultural and linguistic diversity.[1] It is a dynamic, place-based aspect of nature arising from links and feedbacks between these different diversities.[2] There is a strong co-occurrence of linguistic and biological diversity in regions containing many of the Earth's remaining species .[3,4] Biodiversity, cultural diversity and linguistic diversity are thus interconnected and have co-evolved as social-ecological systems.

Indigenous Peoples and Local Communities (IPLCs) are communities of speakers of highly endangered languages that live in areas with the highest biodiversity. Most of these IPLCs are critically endangered by the same forces that threaten biodiversity.[5] Their languages are carriers of their sociocultural knowledge systems as well as encode traditional ecological knowledge that is instrumental in preserving and sustaining their natural habitat. Just as these languages, cultures and worldviews are threatened with extinction, so too are the associated knowledge systems that are linked to and sustain biodiversity. IPLCs, therefore, play a crucial role in the sustainable use and conservation of biodiversity and ecosystems. They also hold diverse worldviews, values, institutions, and governance systems that are crucial to the conservation of biocultural diversity and sustainability. [6,7] Sophisticated environmental knowledge systems held by IPLCs are relevant for informing

Most of the

**7,000**

known languages in the world are threatened with extinction.

There are about

**5,000**

indigenous peoples with their own socio-cultural traditions. As hunters, fishermen and gatherers, they depend on an intact environment.

About

**70%**

About 70% of the world's languages are spoken on about 24% of the earth's terrestrial surface, which comprise the remaining regions of high biodiversity.

and guiding scientific research, development projects, conservation and environmental policies, and bioeconomy initiatives.[8] Recognizing IPLCs' rights to their territories and resources, therefore, is not only fundamental for the maintenance of biodiversity, but also for the preservation of sociocultural and linguistic diversity.[9]

Although many indigenous/local languages, their associated knowledge systems, and biodiversity are under pressure of the same forces, there are not only similar reasons for the loss of languages and the loss of species, but there is also a feedback effect. For with the decline of linguistic competence in indigenous/local languages, the knowledge of the biological world, which is stored in the lexicon of these languages, also declines - and this can have an influence on the diversity of species. In the lexicon of a language, important aspects of the cultural knowledge of a linguistic community are preserved. It is often not easily transferred to another language.

In a study of 236 languages from North America, Amazonia and New Guinea, it was found that well over half of medicinal herbs are known only in one language and not in any of the neighbouring languages. This shows that the unique knowledge of the healing power of plants will be lost with the extinction of languages.[10] Another study shows that language attrition is accompanied by a decline in the traditional knowledge of natural habitat.[11] The study examined the language competence of over 6,000 students and their parents in Papua New Guinea – almost 400 languages were represented. The study examined biocultural competence and found that varied medicinal plant uses known to the students speaking indigenous languages are replaced by a few, mostly nonnative species for the students speaking

English or Tok Pisin, the national lingua franca. There is thus a direct link between the decline in linguistic competence and the loss of knowledge about the biological environment.

**Background**

As with global biodiversity, the world's language diversity is under an immense threat.[12] Of the 7,000 languages known to date, almost half of them are considered endangered.[13] By way of comparison: Roughly 41 per cent of amphibian species, 26 per cent of mammals and 13 per cent of birds are currently threatened with extinction.[14] The most pessimistic predictions suggest that 90% of the world's languages will be lost within a century.[15] The United Nations proclamation of 2022–2032 as the International Decade of Indigenous Languages aims to raise global awareness about their endangerment and importance for sustainable development. Indigenous/local languages contain the knowledge that communities have about their surrounding ecosystems. This knowledge is often not known outside of the small speech communities where most endangered languages are spoken.

Many indigenous/local languages are critically endangered by the same drivers that threaten biodiversity. Just as these languages, cultures, and worldviews are in danger of extinction, so are the associated knowledge systems that are linked to and sustain biodiversity. The IPBES global assessment has revealed that 72% of the indigenous indicators "show ongoing deterioration of elements of nature important to them".[16] Recognising the multiple interconnections between sociocultural and biological diversity is essential to the pursuit of sustainability and environmental justice. Biocultural diversity manifests itself in the languages, worldviews, livelihoods and deep historical linkages that exist between IPLCs and their respective ecosystems. Diversity in all its forms must be understood as a value to be cherished, fostered, promoted and protected.

!

## Policy recommendations

1. Recognize the land, territorial, and sociocultural rights of IPLCs, in connection to policies that value and support ecosystem-based livelihoods (e.g. UN Convention ILO 169).
2. Support the documentation and preservation of indigenous languages and related knowledge systems as living manifestations of endangered biocultural diversity.
3. Develop strategies to raise public awareness of indigenous languages, including concrete actions for language revitalisation and conservation, integrated with biodiversity conservation actions.

## Societal recommendations

1. Indigenous languages, cultures, religions, and other aspects of indigenous life should be respected by society in general. This requires adequate educational curricula, awareness campaigns, and replacing stereotypes and myths with reliable information. Only a public informed about diversity and its advantages is in a position to value, defend, and help preserve it.
2. Unsustainable economic development should be avoided and, instead, alternatives based on the traditional ecological knowledge of indigenous/local communities should be offered, taking into account their intellectual property rights.
3. As it is currently estimated that more than half of the world's population is multilingual, multilingualism should be viewed positively and not as an obstacle, both by society as a whole and by indigenous/local communities themselves. One does not have to abandon one's native language to learn a national language.

# 5 Using forests sustainably

1 Well over half of the biomass stored in European forests (58 per cent) is vulnerable to disturbance by windthrow, fire and insect infestation. These disturbances tend to increase in frequency and intensity as climate change progresses.

2 After three years of drought in a row (2018-2020), 79 per cent of all trees in German forests show signs of crown defoliation. Against the background of ongoing climate change, this damage makes it even more difficult for forests to provide a wide range of *ecosystem services*, and requires innovative concepts for adaptation.

3 Managed forests have to meet diverse and often competing land utilization demands, e.g. *bioeconomy* or nature conservation. Resulting conflicts between management objectives can, for example, be at least partially resolved by the spatial zoning of different management intensities.

4 Species- and structure-rich forests are *more resilient* to disturbances and future climate change, and provide more diverse ecosystem services.

5 Disturbances are part of natural forest development and can increase both species- and structural diversity. They can, therefore, also be seen as an opportunity for forest adaptation.

## Sustainable forest management is more important than ever, in order to use forests and their products sustainably, to safeguard multiple ecosystem services and ensure climate and biodiversity protection, and to support the adaptation of forests to climate change.

Sustainable forest management faces the great challenge of meeting multiple demands at the same time: to meet the increased demand for traditional wood products, but also for the bioeconomy (e.g. sustainable energy, construction, chemical industry), promoting *climate-resilient forests* that are largely resilient to increasing disturbances such as windthrow, fire and insects, thus contributing to climate change mitigation and greatly reducing biodiversity loss[1] (> MustKnow1). *Primary forests* must be protected from deforestation, while proven forest management in *secondary forests* and near-natural forests can provide a wide range of ecosystem services in a sustainable manner. Plantations that are cleverly embedded in the landscape – and intensively but sustainably managed – can take the pressure away from more natural forests.

Globally, disturbances are part of natural forest dynamics, but these have increased in recent years, so forest fires have become more extreme. In European forests, windthrow, fire and insect infestation are the main disturbances. They are exacerbated by simplified forest structures and tree species composition – legacies of traditional forestry of past centuries. Massive insect infestations, in particular, have occurred more

After the drought years of 2018-2020,

**79%**

of all trees in Germany show signs of crown defoliation.

In German forests in 2019, at 32 million cubic metres, more than

**5x**

of damaged timber in total harvests was felled than in 2017. The share of damaged timber in total harvests was 67 per cent in 2019, more than three times as high as in 2010 (19.7 per cent).

**2/3**

of globally absorbed carbon is stored in temperate and boreal forests. Secondary and close-to-natural forests play a large part in this.[15]

frequently since the year 2000. Almost 60 per cent of the forest biomass is vulnerable to these disturbances. This could potentially lead to a total loss of about 33.4 billion tonnes of biomass in Europe.[2] German forests are also suffering from more frequent disturbances in general.[3] The severe drought from 2018 to 2020 affected many forest stands over large areas, and triggered a debate on how to deal with the affected areas and which methods are particularly suitable for reforestation.[4–6]

Natural regeneration, or regeneration supported by planting, also increases the resilience of forests on disturbed areas. If deadwood remains on these areas, part of the carbon can be stored in the soil in the long term and thus removed from the atmosphere. At the same time, regeneration creates a diverse habitat for many different animal and plant species, and additional carbon is sequestered in the forest ecosystem.[7] Depending on local conditions and requirements (regeneration of a managed forest under advancing climate change or focus on erosion control), different measures may be appropriate to promote diverse and resilient forests.

At the same time, it is important to define an appropriate mix of tree species that – taking into account the uncertainties of climate projections – defy climate change or spread the risk. It is not always sufficient to rely only on natural regeneration. Rather, the chosen mix of tree species must be resilient under a future climate that will be warmer and in which extreme weather events are expected to be more frequent. Therefore, it can also be purposeful and necessary to increase diversity and management options by means of targeted plantings. Attention must be paid to species-specific characteristics such as drought tolerance, rooting depth, susceptibility to *pathogens* and insects, and at the same time the invasiveness of new tree species.[8]

Even if a multifunctional use of many forests is the goal, zoning of different management intensities can represent a solution to meet the diverse societal demands and protect biodiversity at the same time. Zones of intensive and extensive management can be spatially contiguous with natural, unmanaged forests, thus enabling better process and biodiversity protection.[9] Nevertheless, it should be noted that sustainable forest management can also have a negative global impact on biodiversity, as timber production and harvesting influence forest-dependent species. Even in scenarios for sustainable land use and timber harvesting intensity (*SSP1*), biodiversity losses, albeit in a weakened form, are to be expected from an expansion of European managed forests.[10] On the other hand, sustainable forest

In European forests, windthrow, fire and insect infestation are the main disturbances. They are exacerbated by simplified forest structures and tree species composition – legacies of traditional forestry of past centuries.

## Global future projections assume a further increase in demand for land and timber, which makes it more difficult to reconcile forest use with biodiversity conservation.

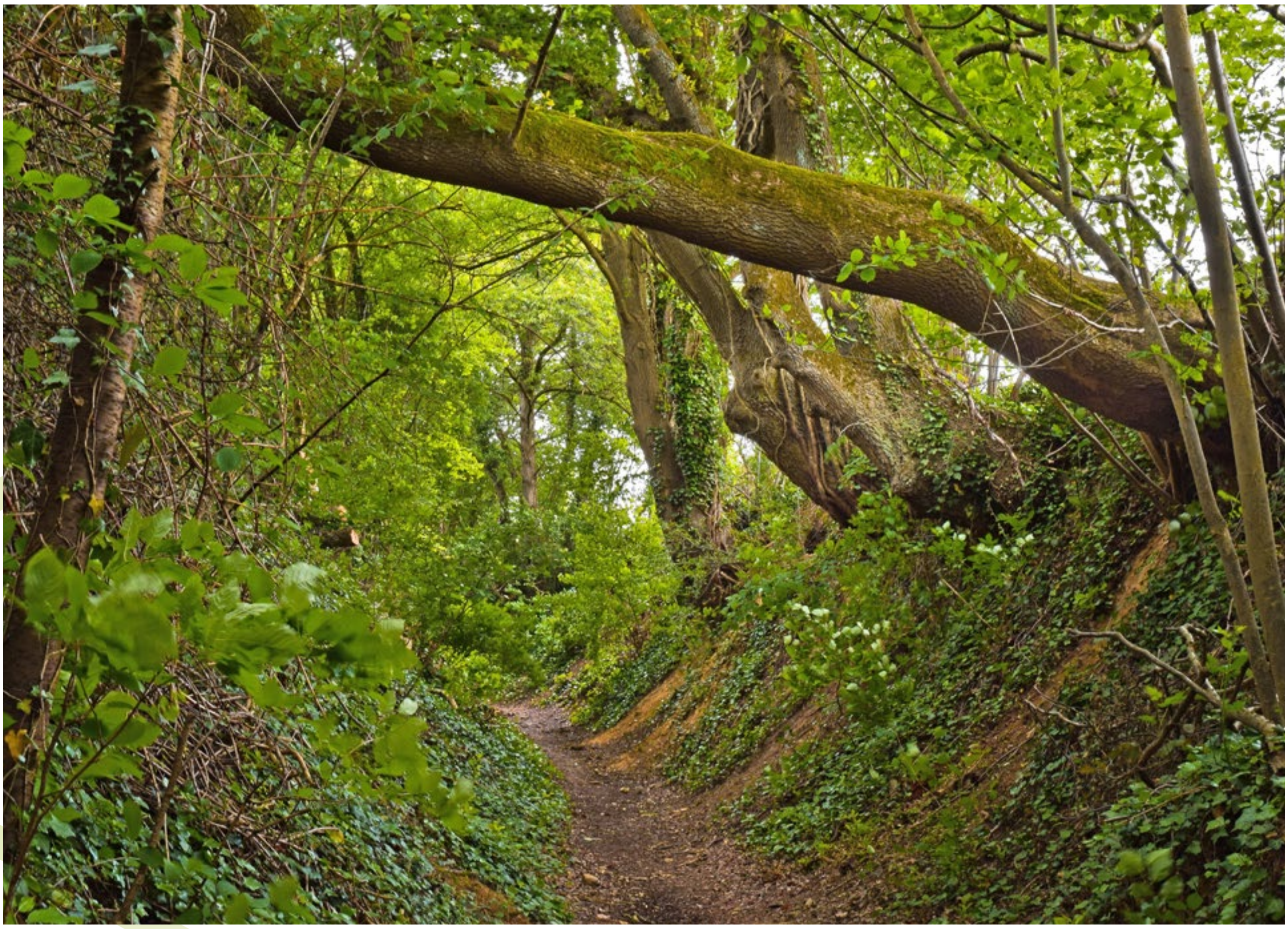
management can also make existing commercially exploited forests and plantations more species-rich by creating diverse habitats.

High demand for timber resources combined with strong protection of domestic forests poses the risk of outsourced timber extraction to often insufficiently protected primary forests (e.g. in Siberia[11] and in tropical dry forests[12]), so that these then turn from carbon sinks to carbon sources.[13] Forest, environmental and trade policy must, therefore, take greater account of the global interconnectedness of timber production, but, in particular, a *coherence* of cross-sectoral measures is required, in order to better balance conflicting goals with other ecosystem services of managed forests.

**Background**

In order to meet the diverse societal demands and, at the same time, find suitable measures for sustainable forest management, a variety of factors must be taken into account, which can look very different at local and regional level. Social factors (history of use, ownership), economic factors (value chains, costs of silviculture), ecological factors (climate change, soil, tree species) and global factors (timber trade, environmental policy) define the framework conditions, requirements and opportunities for sustainable forest management.

The consequences of increasing climate extremes vary from region to region. Forests in Germany have suffered greatly from drought and heat waves in recent



years. Bark beetles such as the European spruce bark beetle (*Ips typographus*) can reproduce at a particularly fast rate in already weakened trees, and kill trees over a wide area. This can be dangerous for entire forest landscapes. In 2019, 32 million cubic metres of timber was felled due to insect damage, almost three times as much as in 2018, compared to only six million cubic metres in 2017. At 67 per cent, the share of damaged timber in total logging in 2019 was more than three times higher than in 2010 (19.7 per cent).[14]

Global future projections assume a further increase in land and timber demand that are increasingly difficult to be reconciled with biodiversity conservation. In scenarios projecting future socio-economic development, the areas required for planted, more intensively managed forests and possible further losses of near-natural managed forests were analysed for the first time. Even though these global simulations are subject to high levels of uncertainty, they nevertheless show that, even under sustainable future scenarios for socio-economic development, seven per cent more managed forest area would be needed globally in 2050 compared to the year 2000. These changes would result in species losses even in the sustainable scenario.[10] Higher demand for wood products could also mean that biodiversity losses would be caused by the deforestation of insufficiently protected primary forests in other regions. These could be quite different depending on the continent. For example, one study[11] reports large losses in the taiga region due to increased demand for timber in China.

## Policy recommendations

1. Natural regeneration supported by plantings must, above all, promote tree species that are better adapted to climate change (drought tolerance, rooting depth, susceptibility to pathogens and insects) and thus favour mixed forests.
2. The global protection of primary forests is essential for the conservation of biodiversity and the stabilisation of the Earth's climate. By spatially zoning different management intensities, managed forests can also reduce harvest pressure on primary forests while providing diverse ecosystem services.
3. Solutions for managed forests must take into account the conflicting goals resulting from multiple demands (bioeconomy) and requirements (biodiversity protection and climate adaptation), as well as the governance structures in individual countries.

## Societal recommendations

1. Open areas created by disturbance and deadwood left there provide important habitats for many species that find their growth niche here during the natural regeneration of the forests. At the same time, it must be considered how the existing forest structures in managed forests can be diversified and made more resilient, in order to enable adaptation to climate change.
2. An end to deforestation of primary forests, especially in the tropics, should be a top priority. Activities that consistently support this goal should be strengthened. In regions with predominantly managed forests, however, management can also contribute positively to the conservation of diverse ecosystem services (including raw materials for a circular economy) if it is embedded in sustainable forest management.
3. Solutions for sustainable forest management – when coordinated at all levels – must also consider trade and the associated risks for outsourced nature losses and forest degradation. Forest certification can offer a way to promote the sustainable use of forests by changing consumer behaviour. These certifications must be credible and continuously evaluated, in order to prevent misuse.

# 6 Transforming agriculture

1 Agriculture is a major contributor to the loss of biodiversity and, conversely, can make a significant contribution to the protection and promotion of biodiversity.

2 Various cultivation methods and new forms of management use biodiversity as an important and nature-based production factor, and can specifically promote the conservation of biological diversity.

3 Productivity can be increased independently of land area, and thus decoupled from an expansion of agricultural land.

4 Financial incentive mechanisms and advisory services, combined with social awareness raising efforts, stimulate biodiversity-friendly agriculture.

## Farmers are crucial stakeholders in the conservation and advancement of biodiversity.

The expansion of global arable land and the increasing intensification of agriculture are having a far-reaching negative impact on biodiversity.[1,2] Agriculture can now not only be described as the largest geoengineering measure in human history, but it is also considered the main driver of biodiversity loss. The trend towards more intensive production has been accompanied in many countries by the establishment of larger farm and field sizes, the expansion of cultivated areas, reduced crop diversity and the loss of biodiversity on the land being used, as well as in its surroundings.[3,4] Current research highlights that growing mixed crops over a longer period of time with lower inputs leads to more stable and, on average, higher yields.[5,6,7] Increased plant diversity on cultivated land increases the diversity of other organisms (e.g. insects, microbes).[8,9] Diverse crop rotations, the cultivation of catch crops, the integration of protein crops or rediscovered crops not only improve soil fertility, but also promote the genetic diversity of species and thus more diverse agricultural landscapes. A diverse mix of farming methods is usually accompanied by increasingly versatile forms of farming that are more *resilient* to weather and price fluctuations. At the same time, new forms of production complement traditional agriculture. And so, e.g. starch can be produced by chemo-enzymatic synthesis from $CO_2$ and hydrogen in cell-free systems.[11,12,13]

Previous calculations on agricultural production do not take into account the economic value of biodiversity, which is a crucial production factor (> MustKnow10). The loss of biodiversity is already jeopardizing yield levels in agriculture. The societal costs of biodiversity loss through agriculture are currently not (or only insufficiently) taken into account. Targeted financial incentives, such asresult-oriented remuneration for the conservation or development of biodiversity, or cooperative financing models, are necessary building blocks for biodiversity-promoting agriculture.[14] On the part of both producers and consumers, advice and targeted information are essential preconditions for forcing the necessary social change.[15]

## Previous calculations on agricultural production do not take into account the economic value of biodiversity, which is a decisive production factor.

## Agriculture provides a wide range of services for nature and society, but these services also compete with each other. Resolving conflicting goals that arise is a challenge for politics and society.

*Intensive land use* should not be excluded, in principle, but biodiversity-promoting measures – such as a wide crop rotation and reduced tillage – should also be included on intensively used land. This increases the level of functional diversity and guarantees the preservation of ecosystem services. Agricultural land for agricultural and public goods, defined with a clear objective of production – such as securing clean groundwater, fertile soils and biodiversity – promotes productivity and diversity in the long term. Biodiversity is thus specifically used as a decisive production factor in a systemic approach for increasingly diverse and stable crop production.

Climate and biodiversity protection must generally be addressed collectively and holistically, for a transformation of agriculture (> MustKnow1).[16] Without climate protection, efforts to conserve biodiversity will not be successful in the long term.[17,18]

**Background**

The intensification of agriculture through the use of mineral fertilisers, synthetic chemical pesticides and the cultivation of higher-yielding crop varieties has increased agricultural production enormously since the 1950s. In addition, over the past 20 years, agricultural land has expanded globally by nine per cent compared

The dominance of a few cereals: Cultivation of maize, wheat and rice on

**40%**

of globally harvested areas.

Agricultural subsidies:

**540bn.**

US dollar globally at present.

Life-essential plants: Up to

**39%**

of plant diversity is considered "threatened with extinction".[26,27]

to 2003 – natural vegetation and forests have disappeared.[19,20]

Agricultural production, which is primarily geared to economic requirements, endangers biodiversity and ecosystem functions (e.g. soil fertility and carbon storage) not only on agricultural land, but also in the surrounding habitats. Globally, production methods are becoming ever more similar, field and farm sizes are steadily increasing[21], and the diversity of the crops grown is decreasing. Maize, wheat and rice, for example, account for 40 per cent of global cultivation.[22] This goes hand in hand with an increased cultivation risk, because e.g. fewer micronutrients are available, or there is an increased incidence of disease.[23]

The conservation and improvement of the gene pool of flora and fauna is also of great importance for human health (*One Health*).[24,25] Providing enough food for a balanced diet for a growing population with decreasing agricultural land per capita poses great challenges for agriculture. These can only be solved through biodiversity-friendly management and the use of biodiversity. Incentives for healthier diets that also use less land resources are an essential building block in this endeavour.

Agriculture also provides a wide range of services for nature and society, but these services also compete with each other. Resolving conflicting goals that arise is a challenge for politics and society.

!

## Policy recommendations

1. The use of biodiversity and diverse ecosystem services as nature-based approaches for agricultural production are increasingly required and should be promoted. Existing subsidies must be used specifically for the transformation of agriculture towards biodiversity-friendly production.
2. The values of biodiversity in agriculture must be made visible, cause-related costs must be taken into account and the valorisation of biodiversity services must be promoted.
3. Agriculture as an important economic and socially relevant sector of tomorrow's world and the starting point of a sustainable value chain or value network must be transformed.

## Societal recommendations

1. The work of farmers as providers and maintainers of biodiversity should be valued.
2. There is a need to develop a fundamental understanding of the consequences of one's own consumption and lifestyle behaviour for biodiversity and climate.
3. Raising social awareness contributes to more health- and environmentally-conscious eating behaviour and thus promotes more sustainable, biodiversity-friendly agriculture.

# 7 Protecting land and resources

**1** Land- and resource-relevant decisions can only be made by means of procedures that generally involve all affected stakeholders in the decision-making process. The attempt to calculate the services of natural resources or *ecosystem services*, respectively, including biodiversity, in purely monetary terms ignores the many non-monetary services at hand.

**2** This complexity renders it difficult to weigh up decisions and to set economic incentives that actually achieve the goals. Previous strategies have not been able to stop the steady loss of species and resources. Globally, the sharp increase in resource (excess)use is fundamentally changing almost all ecosystems, with difficult or unforeseeable consequences for biochemical cycles and the biosphere as a whole.

**3** The EU has not met its target of halting the net loss of biodiversity by 2020. In order to minimise the (excess)use of resources globally and to make global interdependencies and impacts sustainable, legally binding sustainability standards and targets are necessary. This applies to certifications, for example. The need for action (in the EU and worldwide) is becoming increasingly urgent.

**4** Biodiversity conservation must no longer be one goal among many. In future, the protection and improvement of biodiversity must be given greater (including legal) weight in key policy-making decisions: A clean and healthy environment is a human right.[1] This fundamental right must be supported with binding international, national and municipal targets, as well as clearly delineated responsibilities.

## In order to preserve biodiversity, a sustainable use of resources is required, in particular, a sustainable use of land and water resources by direct users, as well as a clear political and legal framework.

Existentially critical land use-, water- and biodiversity crises can only be solved in coordinated, cooperative and integrated processes. Without a social discourse on viable ways for more resource protection, and without a clear political prioritisation of this issue, these major crises remain the elusive "problems of others". Water and agriculture are part of the solution here. They are considered central stakeholders (> MustKnow6). However, serious adaptation measures are needed, e.g. a complete change of subsidies in European agricultural policy.[2] However, European (and ultimately global) policy can only be implemented effectively if regional and local stakeholders are actively involved. In this way, pioneers of change – from niche to mainstream – can establish themselves and shape future decisions for biodiversity, more sustainable water and land use (agriculture and forestry) and greater climate protection.

For coordinated, cooperative and integrative procedures to work, a binding attribution of joint responsibility and corresponding tasks is required. Known, feasible alternatives to "business as usual" must be seriously considered as solutions. An integrated discussion approach, in order to avoid interventions in biodiversity, is indispensable, if only because considerable financial resources will be necessary, for example, to *renaturalise* and protect ecosystems, or to design effective solutions to compensate for use. However, Agricultural policy – the key ingredient: Pesticide use has an immense impact on biodiversity. Researchers found significantly higher plant biodiversity in fields that had been cultivated organically for many years than in conventionally cultivated fields.[25]

**53:3**

**77%**

of land area (excluding Antarctica) and 87 per cent of the ocean have been altered by direct impacts of human activity (50 per cent of which are considered very intense). And the knock-on effect: 83 per cent of the biomass of wild mammals and 50 per cent of the biomass of plants.[23]

Aquatic biodiversity is also confronted with serious changes due to climatic changes or (international) intensification of use. In the meantime, for example, more than

**80%**

of the living organisms in the Rhine are invasive species (including small organisms such as larvae, mussels or snails).[24]

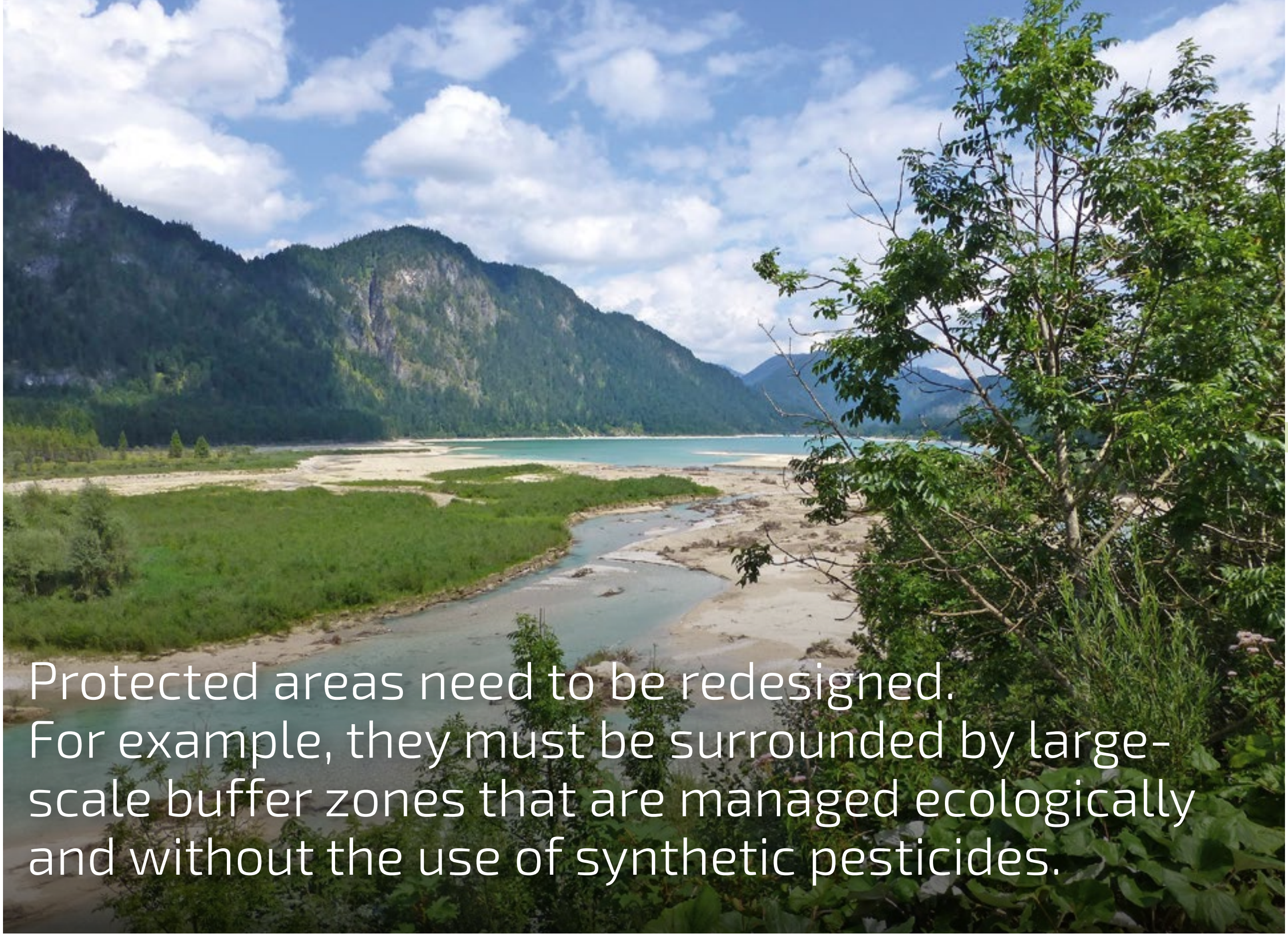
these investments can pay off quite quickly, e.g. by the accompanying benefits of climate change adaptation, or the mitigation of its impacts[3] (> MustKnow1, 8).

Stopping the (excess) use of resources and its effects – for example, on species composition within *biocoenoses*, biotopes or ecosystems, on their dynamics, stability and interconnections – has not yet been sufficiently successful. However, they are shifting more clearly into political and social focus because of their scale and speed. More sustainable water management is needed to end the ever-increasing rate of excess use, damming, pollution and *eutrophication* of natural waters, and to pay more attention to blue infrastructures (water bodies).

The TEEB study can be regarded as an approach to illustrate the value of ecosystems. It has provided the impetus for further projects on the recording and valorisation of ecosystem services.[4] In this context, it also became clear that the importance of ecosystems and biodiversity for human well-being (*Human and Ecosystem Health*) is difficult to grasp in financial terms – many ecosystem services cannot be expressed in monetary terms. Follow-up projects concretise this topic explicitly for planning and spatial development (e.g. ÖSKKIP-Project).[5] But even if the economic value of biodiversity and resources – such as soils and waters – cannot be fully captured, this is no excuse not to work hard for their protection, health and sustainable development (> MustKnow3, 5, 9).

Resource-damaging economic models are "business as usual" with strong inertial forces. In order to minimise the (excess) use of resources, responsibilities and jointly defined, binding goals must be identified and consistently implemented. For this, it is important to have a binding monitoring function in place to ascertain how resources are used.[6] Decoupling economic growth from resource use is a goal of the European Green Deal. The EU Biodiversity Strategy 2030 identifies four approaches to reduce the effects of resource use in its Target No. 6 "Help stop the loss of global biodiversity".[2] Changing European production and consumption patterns are cruxial to this concern. This is because conservation concepts (on "exclusive" areas) alone cannot stem the loss of biodiversity. Especially given that, even in nature reserves, insects, for example, are heavily contaminated with pesticides.[7] Protected areas must be redesigned; they need to be surrounded by large-scale buffer zones that are managed ecologically and without the use of synthetic pesticides. Overall, the hugely extensive use of pesti-

An integrated discussion approach that aims to avoid interventions in biodiversity is indispensable, if only because considerable financial resources will be needed, for example, to renature and protect ecosystems, or to design usage compensation measures.






cides must be reduced. Worldwide, however, protected status is defined, interpreted and implemented very differently, zoning concepts do not necessarily include all necessary ecosystems. (>MustKnow3) Often, there are not enough resources (financial, logistical and human) available to manage protected areas effectively and sustainably, and to integrate the local population.[8]

Biodiversity conservation must be an integral part of responsibilities and actions at all levels. The socio-ecological transformation requires the state to commit to the conservation, protection and development of the resources of soil, water, air and biodiversity. Laws, planning bases and instruments must be extended, in order to prioritise the protection and development of functioning ecosystems, at all planning levels. Existing compensation instruments should be adapted accordingly. The strongest instrument of area nature conservation is the *Intervention Compensation Regulation*, which follows the prohibition of deterioration.[9] This prohibition should be supplemented by an improvement requirement (*Net Gain*)[19/11], in order to achieve a plus or an increase in biodiversity and ecosystem services at the end of interventions in nature and landscape within the framework of compensation – and not only to prevent a net loss. The European Soil Strategy includes the goal of net zero land use by 2050.[12] However, this ambitious goal is not being addressed in a coordinated or multidisciplinary manner in the Member States. On the contrary, it seems unrealistic due to progressive new land use, soil sealing and degradation. The EU Member States have committed themselves to protecting 30 per cent of the area of the North and Baltic Seas for marine flora and fauna. In Germany, the management plans for the protected areas in the German Baltic Sea came into force in February 2022 and must be implemented quickly.[13]

**Background**

Finally it is unclear what resource consumption humanity can still "afford" if the biosphere is to remain stable. The factors on which an assessment depends are extremely diverse. With a growing world population, changing per capita consumption, the catching-up of mechanisation and industrialisation, political instability in many key countries to biodiversity and the manifold, incalculable effects of climate change on ecosystems, types of land use and societies, effects are taking on a life of their own, and social, political or economic consensus must be sought to manage them.[14] However, a "business as usual" approach is by no means conceivable.[15; 16]

Climate change, loss of biodiversity and the crisis of water and land use are interrelated phenomena whose projected development accelerates other crises (including migration, poverty, global injustice, lack of access to basic foodstuff). [17;18] Climate change and biodiversity loss are mutually reinforcing; addressing one problem requires addressing the other.[19] Thus, biodiversity hotspots are increasingly threatened in their central functions for the global climate by the regional and local consequences of climate change (> MustKnow1).

Restoring carbon and species-rich freshwater, terrestrial and marine ecosystems helps to mitigate climate change, increase water retention, protect biodiversity and support adaptation to climate change.[20;21] Due to the complexity of ecosystems, scenarios that project their development are not yet as advanced as scenarios on climate change. Climate protection measures can, therefore, not yet be fully assessed with regard to their impact on biodiversity scenarios. In order to increase the effectiveness of biodiversity conservation measures, science is working to improve biodiversity scenarios.

For political engagement, it is central to initiate processes of social understanding based on scientific findings, to overcome post-factual illusory discussions and to point out possible solutions in a comprehensible way. For this, global goals must be jointly defined and addressed or operationalised at national, regional and local level. The World Biodiversity Council (IPBES) has presented a blueprint for this, in which progress with regard to resource use can be methodically recorded and globally balanced. Binding and accepted data base is necessary for this. This strategy can overcome the strong forces of inertia and promote the global and effective protection of biodiversity, as well as a fundamental change in land and water use.

## Policy recommendations

1. Given that all human activities affect soil, water and ecosystems, resource protection must be seen as an interdisciplinary goal and responsibility. It must be afforded prioritised consideration as a global task in all political and planning decision-making processes, and must not be undermined by individual interests.
2. The promotion of innovative social forces (*Change Agents*, multipliers and creative science-based projects) is a central building block of a transformation to becoming a resource-conserving society and economy that understands natural resources as finite and precious, consistently protects them and constructively supports the dialogue on this matter.
3. The implementation of the planned *Action Programme "Natural Climate Protection"* is important because it should create synergies between nature and climate protection and strengthen the resilience of ecosystems. Concepts such as the circular economy should be implemented in as low-threshold a manner as possible, with adequate funding and in dialogue with society as a whole.

## Societal recommendations

1. Resource protection must be more deeply anchored in the general conscience as a central social concern, and it must be more effectively promoted. A profound, transformative change in the management of biodiversity and natural resources is needed.
2. Critical reflection and changes in the individual's own consumption behaviour, eating habits and sustainable use of natural resources are also good examples of people's capacity to contribute to the protection of biodiversity and limit climate change. This requires clear political backing (see above).
3. Courage and the will to innovate are needed and must be explicitly supported in the political sphere. The vision of a good life that sees responsibility vis-a-vis nature as central, and which promotes the common good and health is realisable: for a turnaround in prosperity and consumption.[22]

# 8 Expanding transnational infrastructures and education for sustainability

1. Comprehensive biodiversity conservation requires going beyond traditional, state-based considerations. Outsourced biodiversity losses must be tracked along the production chain and taken into account in the life cycle assessment of products.

2. The EU Biodiversity Strategy 2030 can only be successful if other policy sectors incorporate nature conservation, e.g. through sustainable agriculture, the reduction of environmentally harmful subsidies and integration into climate, health or foreign policy.

3. Standardised biodiversity monitoring and open data exchange (> MustKnow9) are indispensable for developing transnational and global strategies. Standardised biodiversity monitoring systems that combine established observation methods with modern, automated methods such as *eDNA*, automatic image recognition or remote sensing, enable the recording and analysis of global trends in a timely manner. They create the basis for taking effective measures to protect and restore biodiversity.

4. More than 70 per cent of all biodiversity data is collected by people active outside academic science. *Citizen Science* can, on the one hand, collect extensive, large-scale data sets in space and time, and complement governmental biodiversity monitoring. Citizen Science, on the other hand, can also contribute to facilitating an increased awareness of the value of biodiversity among the population.

5. Based on existing national and international structures, transregional biodiversity monitoring systems and global networks need to be developed. Collecting biodiversity data on a global scale allows us to capture changes in biodiversity and its drivers. At the same time, regional and local citizen science networks and national professional societies need to be strengthened, in order to train more people and build capacity in taxonomy, in order to carry out collaborative monitoring.

Biodiversity and ecosystems know no political boundaries: Biodiversity research and monitoring, specific measures to protect biodiversity and communication between different stakeholders require cooperation that extends far beyond national borders.

Socio-economic and ecological interactions between distant, yet coupled human and natural systems have increased in scale and intensity in the era of globalisation (> MustKnow1). The integrated framing of *telecoupling*[1] examines the flows of information, energy, matter, people, organisms and other things such as financial capital, goods and products around the globe. It reveals the causes and effects resulting from the engagement of different stakeholders in a global space. This approach also makes it possible to identify outsourced biodiversity losses. Trade agreements must explicitly take into account the negative impacts

More than 1,600 dams and weirs have been removed in the USA, and in Europe the number is almost

**5,000**

Nevertheless, many free-flowing rivers remain threatened by dam projects.

Cititzen-Science programmes in seven states in the USA deliver more than

**50%**

of observations for common water quality measurements (visible water depth, nutrients and algal biomass). They contribute to the majority of the long-term monitoring (more than 15 years) for selected measurements in lakes.

The Natura 2000 network is the world's largest network of nature conservation areas and currently includes (as at end of 2020)

**18.5%**

of the land surface area and 8.9 per cent of the ocean area of the European Union.[21]

on the environment and people, and contain sustainability commitments.[2]

Natura 2000 is the largest coordinated network of protected areas in the world. It includes inland waters, marine and terrestrial systems and shows how nature and species conservation can be implemented at international level, for example, in the EU Biodiversity Strategy 2030. Prioritising protected areas based on scientific evidence leads to greater *coherence*. Standardised evaluations allow comparisons to be drawn between countries and the aggregation of data.[3] Nevertheless, this network is not sufficient to halt biodiversity loss.[4] Moreover, it does not compensate for the effects of climate change, the influence of land-use change and overexploitation, and the immigration of *invasive species*. In the EU Biodiversity Strategy 2030, coordination between states needs to be strengthened, e.g. by harmonising the protocols for recording biodiversity and the underlying data.[5] In addition, easily accessible infrastructures are needed to make the data collected available and comparable across the EU.[6] The collection of data on farmland, as well as a quantitative assessment of direct drivers of biodiversity change on the ground, must be ensured. Biodiversity conservation must be taken into account in other policies and sectors and funding must be increased, especially in biodiversity management.[4]

The implementation of global goals at national level must be traceable and verifiable. This should be done through coordinated national and global biodiversity monitoring systems, combined with evidence-based indicators.[7,8] However, the collection of data is limited to certain *taxa* that are easily detected and recorded.[9,10] Systematic monitoring across countries should include coverage of invisible diversity (> MustKnow3). It plays an important role in the conservation of ecosystems, *ecosystem functions* and *ecosystem services*.

Biodiversity monitoring must include the monitoring of ecosystem integrity and function, and provide information on the drivers of biodiversity change. Capturing the drivers at the location of monitoring allows for the identification and attribution of those factors affecting biodiversity, tracking progress and prioritising actions.

For Citizen Science, three topics related to biodiversity are particularly important: 1. Sampling biodiversity on large spatial and temporal scales, 2. Promoting an understanding of biodiversity in countries of the Global South and remote areas, and 3. Sampling underrepresented and often inconspicuous taxa.[11] Citizen Science provides robust, high quality data that can support decision-making[12], it can fill gaps in biodiversity monitoring[13] and it supports the collection of data over long periods of time.[14] Involving the public in research allows local knowledge to be included and the needs of the population to be addressed.[15]

At the same time, transregional biodiversity monitoring systems and global networks must be expanded. LTER (*Long-Term Ecosystem Research*) monitoring

Trade agreements must explicitly take into account the negative impacts on the environment and people, and contain sustainability commitments.




sites bring together different research groups and enable scientists to record and assess current developments in biodiversity in a timely manner. The selected location profiles are intended to be representative of global development. In the field of freshwater, for example, GLEON (*Global Lake Ecological Observatory Network*) fulfils this role and investigates the effects of global change on lakes. Although these networks claim to capture global development, they are not geographically representative and not systematically distributed across continents and ecosystems. The networks must, therefore, be expanded and strengthened.

Biodiversity monitoring must be organised and networked at different regional levels. In order to enable systematic, global biodiversity monitoring, national networks and biodiversity monitoring must be more robustly interconnected and linked to regional and global networks (e.g. *Global Biodiversity Observation Network* (GEO BON) or EuropaBON). The harmonious integration of systems (interoperability), data and protocol harmonisation and communication between the networks must be improved by way of regular exchange. National infrastructures support the collection of data; regional and global information systems should not only function as data portals. Rather, they should integrate databases that offer the possibility of evaluating and explicitly displaying the data. (> MustKnow9)

International protected areas and wildlife corridors must be promoted. The green and blue ribbons – or the idea of dark infrastructures to protect corridors from artificial light barriers[16] (> MustKnow3) – are in urgent need of transnational cooperation to ensure the linkage (connectivity) of protected landscapes, wildlife corridors and waterways. In highly urbanised areas, the implementation of protected infrastructure is important, in order to improve living conditions and counteract the negative effects of climate change[17] (> MustKnow1).

Best practice examples are valuable, for example, in the planning and implementation of infrastructure projects (e.g. hydropower plants, restoration measures). The assessment of such infrastructures and their functioning urgently requires transnational cooperation and regulations, as, among many other reasons, the increasing interconnectedness of watercourses increases their water storage capacity.[18]

Freshwater ecosystems should be managed and delineated at the catchment level, which are not defined by national boundaries, but by their drainage networks, catchment areas and adjacent systems.[19] Instances of connectivity in ecosystems – vertical, lateral and longitudinal – can often only be achieved through international cooperation and form the basis for comprehensive biodiversity conservation, because the foundation of our ecosystems are often hidden away (> MustKnow3).

### Background

The essential biodiversity parameters (*Essential Biodiversity Variables*, EBVs)[20] provide a standardised framework to capture biodiversity data at different levels of (biological) organisation – from genes, to populations, to ecosystems. EBVs form the foundation for indicators that can be used at national and international level to register and compare changes in biodiversity.[8]

Existing national infrastructures include, for example, the National Research Data Infrastructure for Biodiversity or the Distributed System of Scientific Collections (DiSSCo). Regional and global information systems include the Biodiversity Information System for Europe (BISE) and the Global Biodiversity Information Facility (GBIF).

There is a lack of international organisations for species monitoring, for early warning systems (> MustKnow3) and for the participation of "citizen scientists" in monitoring not only species but also drivers of global change. The UN Office for Outer Space Affairs (UNOOSA), as well as the UN Environment Programme for the Protection of Migratory Species of Wild Animals, call for international cooperation to reduce the negative impacts of artificial lighting. Not only nighttime illumination, but also communication satellites in low-Earth orbit are becoming brighter, larger and more numerous. Calls are growing louder for transnational regulations that stop the negative impact on night sky visibility, the orientation of affected organisms, nocturnal habitats and human health. Different disciplines have already made proposals for this. Global guidelines would be essential for the conservation of species, for the protection of migration routes and also for the protection of the climate (> MustKnow1).

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## Policy recommendations

1. A supra-regional, global and systematically ***stratified*** biodiversity monitoring approach (including drivers) must be established and secured in the long term. Knowledge transfer to underrepresented areas worldwide must take place, in order to close the expansive spatial gaps in global monitoring.
2. An area-wide early warning system for biodiversity (e.g. via eDNA, quasi-real-time recording) must be established. Existing monitoring networks must be expanded, strengthened and secured in the long term.
3. Intergovernmental coordination and cooperation must be strengthened and instances of impact that go beyond national borders (telecoupling) must be taken into account in protection strategies.

## Societal recommendations

1. Citizen Science makes a valuable contribution to science and integrates local knowledge. Citizen scientists in possession of in-depth species knowledge are essential for monitoring species and the drivers of global change.
2. Decisions in one's own country always have an impact on other countries – these must be included in decisions (e.g. in environmental policy).
3. The global drivers of biodiversity loss are not limited by national borders, meaning that transnational action is also needed to counteract species loss.

# 9 Ensuring access and open use of research data

1 Openly shared and freely accessible scientific data on the distribution, composition and status of biodiversity is an essential prerequisite for addressing the biodiversity crisis.

2 International data standards combined with the principles of open science (*Open Science*) enable the efficient, sustainable use and integration of biodiversity data and information at local, regional and global levels.

3 Modern technologies are now enabling researchers for the first time to identify newly discovered organisms or alterations in known organisms (e.g. variants in pathogens) with *genetic sequences* so that they can be identified sooner, characterised more quickly and analysed more thoroughly. This linkage and integration of biological and genetic knowledge requires the free availability of (and access to) *digital sequence data*.

4 Broad-based and joint international efforts are required to make all existing biodiversity data digitally and openly accessible, and to develop and maintain relevant information infrastructures at an international level. At present, substantial parts of our existing knowledge and data on biodiversity have not yet been digitised, or are only accessible to a limited extent. Political, administrative and technical restrictions also limit the use of existing data. This hinders science and development.

5 Digital technologies enable active participation in the discovery, observation and monitoring of biodiversity by society as a whole (*Citizen Science*). Digitisation and outreach work anchor science and research in our society and foster an understanding of biodiversity.

## Biodiversity and ecosystems know no political boundaries – a global, open exchange of primary data and scientific information about life on Earth is essential, in order to successfully address the biodiversity crisis and shape a sustainable future.

Biodiversity and ecosystems do not adhere to political boundaries; instead, the current occurrence and dynamics of all organisms are determined by climatic, geographic, other natural factors and *gradients*. These rarely coincide with current political entities, except perhaps for some large islands (Australia, Cuba, Madagascar) (> MustKnow8). The availability of (and access to) reliable data and information on the state of biodiversity is central to the advancement of science and to our ability to respond successfully to major environmental challenges, especially in light of the continuing decline of species and habitats worldwide, and the increasing threats facing ecosystem functions.

Leading international efforts to create structures and mechanisms for open access to large amounts of biological data through both centralised (*International Nucleotide Sequence Database Collaboration*, INSDC)[1] and decentralised (GBIF)[2] data repositories are fuelling science and development.[1-4] Important advances in biodiversity discovery and characterisation[5,6] and monitoring of biodiversity changes (espe-

The February 2022 version of GenBank, as one of the three major genome sequence data repositories under the INSDC umbrella, includes

**1,173,984,081,721**

gene sequences[24] that are freely accessible and used worldwide.

GBIF currently provides open access to **1,927,599,238** records of finds and occurrences of all groups of organisms on Earth. They originate from the databases of **1,789** institutions and facilities from all regions, and can be used free of charge.[23]

**39**

States jointly fund this globally unique, open and distributed data infrastructure, which has existed since 2001.

TRY – A plant trait database whose data has been openly accessible under the Future Earth umbrella since 2019 – currently offers over

**11 million**

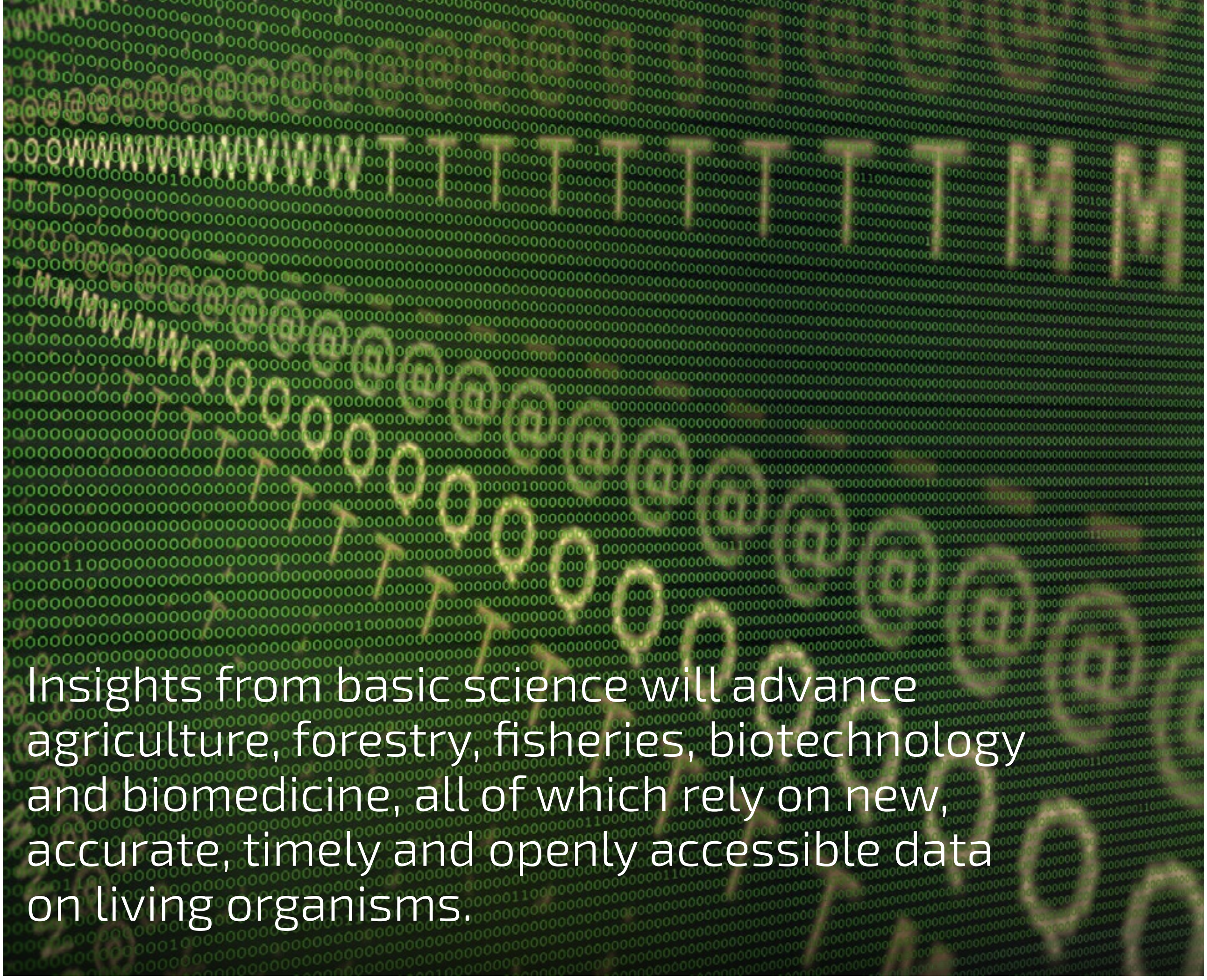
measurement points for 2,100 different characteristics of 160,000 plant species worldwide.[25] It enables global vegetation models to be decisively improved and contributes to Earth system research.

cially for nature conservation)[7-9] have been made possible by these global and open data infrastructures. Further breakthroughs are expected when different data domains are integrated, e.g. *In-situ-data* from extensive biological collections with remote sensing data, as well as the combination of complete *genome* and large *metagenomics datasets*. (> MustKnow8) Digital information science has now matured to the point where it increasingly provides the necessary concepts (and often even the tools) for a holistic view of individual ecosystems and, ultimately, the entire Earth system. In this context, the considerably improved modelling capabilities, in particular, require ever larger, standardised and machine-readable data sources on as many life forms on Earth as possible. Insights from basic science will advance agriculture, forestry, fisheries, biotechnology and biomedicine, all of which rely on new, accurate, timely and openly accessible data on living organisms.

While rapidly developing technologies and tools for digital data collection and analysis are driving progress in the biological and medical sciences and the emergence of more open and participatory science, much relevant biodiversity data is still not available in digital format. Rather, existing data sources and knowledge are widely dispersed, often not interconnected and/or not openly accessible (the "dark matter" of biodiversity knowledge).[5,9]

In addition, increasing tendencies to restrict open access or to "nationalise" biodiversity data and knowledge, e.g. under the Convention on Biological Diversity (CBD), pose a serious challenge to scientific progress and the development of effective plans and actions to address the biodiversity- and environmental crises at hand.[10,11] A protectionist approach to data

Just as the open and rapid availability of reliable weather and climate data is essential to address climate change, fully open and internationally shared and managed biodiversity data and information is essential, in order to conserve and sustainably use biodiversity – indeed the foundation stone of our existence.



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Insights from basic science will advance agriculture, forestry, fisheries, biotechnology and biomedicine, all of which rely on new, accurate, timely and openly accessible data on living organisms.

is counterproductive to those efforts aimed at addressing biodiversity loss and restoring ecosystems.

Therefore, existing and emerging international data networks and infrastructures must be strengthened and kept openly available and re-usable in the long term. Any and all attempts to restrict access to (and the exchange of) biodiversity data must be rejected.

Just as the open and rapid availability of reliable weather and climate data is essential to address climate change, fully open and internationally shared and managed biodiversity data and information is essential, in order to conserve and sustainably use biodiversity – indeed the foundation stone of our existence.

**Background**

Examples of important achievements and developments related to biodiversity data sharing include (among others):

a) GBIF provides free access to more than 1.9 billion bio-datasets of individual organisms worldwide – for all organism groups and countries or areas, respectively. This ever-growing infrastructure for the shared, open use of primary data has significantly increased scientific productivity. Currently, there is an average of one new publication per day based on GBIF-mediated data.[2]

b) Researchers worldwide use digital *genome sequences* from the three large, open *repositories* linked to more than 1,600 databases worldwide under the umbrella of the International Nucleotide Sequence Database Collaboration (INSDC).[12] A recent study on the re-use of 263 million genetic sequence datasets reveals that data feeds and use are globally balanced and highly collaborative.[3] Open access to this networked data is thus enormously beneficial to science.

c) Openly accessible data is relevant for global food security. The analysis of digitally available genetic diversity data, combined with integrating predictive models on environmental traits, lays the foundation for new varieties. Big Data and thus openly accessible data sets form the foundation of knowledge-based plant breeding.[13]

d) New technologies and thematically oriented portals enable the integration of heterogeneous data from different sources. This opens up new ways to preserve biodiversity. For example, the global FishBase portal[14] links basic research data with population and stock forecasting tools for all known fish species, and the Edaphobase[15] data warehouse links data for research and applications on soil zoological biodiversity in Europe.

e) Openly accessible biodiversity data such as, e.g. from the TRY Plant Traits Database, greatly improve predictions of how climate change will affect the future distribution and diversity of animals and plants.[16] This strengthens scientific policy advice and helps to develop better and more sustainable management strategies for many regions of the world.

f) Big Data applications in biodiversity research enable questions about ecosystem functioning to be addressed with high spatial resolution and simultaneously global coverage.[17]

Recent attempts to restrict open access to, and, in particular, the international sharing of, scientific biodiversity data, go back mainly to the Nagoya Protocol under the CBD[10,18], as well as corresponding national laws and regulations.[19,20] Open access to digital genome sequence data is at stake in the ongoing CBD negotiations.[21,22] This represents a major obstacle to international research and development, it contradicts the principles of open science and international scientific cooperation, and risks (further) isolating biodiversity researchers and institutions in the countries and regions concerned – while increased international cooperation is essential for the conservation of biodiversity.

## Policy recommendations

1. International information infrastructures and systems (e.g. GBIF, INSDC, EMBL Bank, OBIS, FishBase), which enable fast and open access to scientific biodiversity data and information, as well as their shared use, must be strengthened, expanded and maintained in the long term worldwide.
2. All attempts to restrict access to (and the exchange of) biodiversity data must be rejected. Open access and unrestricted sharing of scientific biodiversity data from public sources shall be secured through relevant international mechanisms, conventions and agreements.
3. In order to fully digitise and openly share biodiversity data, incentives and adequate resources need to be provided to institutions, infrastructures and stakeholders involved, and relevant information infrastructures and initiatives need to be supported. The use of positive feedback loops (rewards) will further encourage open data sharing.

## Societal recommendations

1. The stronger involvement of different societal stakeholders in the collection and analysis of biodiversity data, as well as in biodiversity research (Citizen Science), is required.
2. Support the free and rapid exchange of biodiversity data and information by making the best use of new and emerging digital technologies and services.
3. Wider access to biodiversity data for all actors is called for, which must respect the rights of individuals and organisations, as well as relevant data protection regulations.

# 10 Setting biodiversity-friendly incentives

1. **Scientific evidence underscores the high economic value of ecosystem services and biodiversity conservation.**
2. **Ecosystem accounting tools are now available as the statistical standard and should be used to incorporate the value of biodiversity into national accounts.**
3. **Policies to conserve biodiversity must take into account the cross-sectoral nature of biodiversity.**
4. **Trade-related linkages make biodiversity conservation an inherently international task.**
5. **Policymakers must remove harmful subsidies that fuel the biodiversity- and climate crisis at hand, and create incentives for public and private investors to invest in biodiversity conservation and restoration.**

## Policies that direct market and investment behaviour towards biodiversity conservation and restoration are crucial to solving the crisis.

The economic value of biodiversity is multi-faceted.[1] Biodiversity underpins and stabilises the provision of environmental public goods, including provisioning, and regulating, and cultural ecosystem services.[2] It can substitute for financial insurance, e.g. against climate shocks[3,4] and – by providing a portfolio of potential future uses – offer an option value.[5,6] Moreover, biodiversity values are sensitive to economic inequality – poorer people tend to benefit more from biodiversity conservation.[7] These welfare effects vary greatly from location to location, depending on the given ecological and socio-cultural context. A global shadow price that covers the societal costs of biodiversity, comparable to the price for $CO_2$ emissions, is, therefore, not feasible. A full mainstreaming of the value of biodiversity requires a profound reform of national accounts to adopt the inclusive wealth framework.[1] Initial steps in this direction have already been taken. Tools for the Convention on Biological Diversity's (CBD) goal of incorporating the value of biodiversity into public decision-making are now standard statistical practice. The United Nations Statistical Commission has adopted ecosystem accounts as part of its system of environmental economic accounts.[8] The German Federal Statistical Office has started to implement the Ecosystem Extent Account and has initiated the Ecosystem Condition Account.[9] Further efforts are required in government statistical offices to incorporate the monetary accounting of ecosystem services and ecosystem assets.

Biodiversity is influenced by a wide range of policies. Not only are direct biodiversity conservation measures important – such as protected areas – but the spillovers from other sectors and policies, including harmful subsidies, need to be given greater consideration. For example, agriculture, fisheries and the food industry, as well as the energy, industry and transport sectors, are responsible for the decline in biodiversity.[10] Sectoral interdependencies also create challenges, as well as opportunities for policy-making. For example, policies that promote the transition to healthier food systems can simultaneously improve outcomes for biodiversity[11] (> MustKnow6), and climate policies can support bio-

Global funding for biodiversity (public and private) is to up to

**143bn.**

USD per year (calculated with data from 2015 to 2017).[1,14]

In 2019, private financiers invested more than

**2.6 trillion**

US dollars in sectors that have a negative impact on biodiversity.[24]

Public subsidies that harm biodiversity amount to

**500bn.**

USD per year.[23]

## The full inclusion of the value of biodiversity in national accounts requires profound reform, in order to shape the framework for inclusive prosperity.

diversity conservation[12] (> MustKnow1). Similarly, trade and trade policy can affect biodiversity, for example, by influencing the import of agricultural commodities from other countries.[13] A holistic, cross-sectoral policy framework is, therefore, urgently needed to halt biodiversity loss.

Globally, public subsidies of between USD 78 and 143 billion are spent annually on biodiversity conservation.[1,14] Most of this funding comes from the USA and the EU, where it is often embedded in other policies. For example, agricultural policy in the USA allocates EUR 5.5 billion annually to important conservation programmes.[15] In the EU, agricultural and fisheries policies, as well as parts of the Natura 2000 network, are regulated at EU level, while other policy areas fall under the responsibility of Member States.[16] Under the EU's Common Agricultural Policy (CAP), EUR 5.3 billion (out of EUR 63 billion, i.e. 8.5 per cent) is allocated to biodiversity conservation.[17] While most of the public money spent under the CAP does not achieve positive environmental impacts, the most effective biodiversity conservation measures tend to receive the least funding.[18]

Environmentally damaging activities shift between countries on a global scale, in order to avoid regulation (leakage). Leakage is difficult to regulate from the perspective of biodiversity protection.[19,20] Unlike the costs of carbon emissions, which are the same regardless of where the emissions occur, damages to biodiversity

**Investments that harm biodiversity outweigh investments that promote biodiversity.**

## The prevailing legal framework contributes to misguiding investment decisions in favour of environmentally detrimental activities.

vary by location and spatial scale. Furthermore, it has to be decided as to whose value standards should be used.[21] For example, should the valuations used in German policymaking be based on the German values for a particular species, or on the values of the population in the area where the species has been lost due to imports into Germany? The most thorough approach is to add up all use and non-use values arising from any biodiversity loss anywhere. However, placing an economic value on non-use values – especially existence values for species in distant habitats – is open to substantial critique. This shows that the information requirements for biodiversity protection that address leakage is large and regulating product value chains with a biodiversity equivalent to adjustments for $CO_2$ emissions is difficult to conceive.

**Background**

The current rate of biodiversity decline is clearly unsustainable.[1] If environmental consumption continues beyond safe planetary limits, it is only a matter of decades before global GDP per capita falls due to environmental

scarcity.[22] This can only be prevented by significantly reducing the conversion of natural capital and thus the decline in biodiversity.

The financial sector represents the epicentre of this crisis. The loss of biodiversity – and the associated reduction of ecosystem services and resilience – can have a significant adverse economic and financial impact. Nevertheless, investment returns do not reflect these risks due to a lack of information and missing (or incorrect) regulations. The prevailing legal framework also contributes to misguiding investment decisions in favour of environmentally damaging activities. Currently, public investments associated with biodiversity loss and ecosystem degradation amount to USD 500 billion per year. This is six times higher than the public and private funding allocated to biodiversity conservation worldwide.[14,23] Private finance that damages biodiversity is five times higher still, estimated at USD 2.6 trillion in 2019.[24] The financial sector must, therefore, play a central role in solving the biodiversity crisis.

Initiatives aimed at improving investment opportunities for financial institutions offer great potential to mobilise capital flows for biodiversity protection and conservation
(> MustKnow6). In order to steer resource allocation in this direction, new investment incentives are required that reflect the economic value of changes in natural capital and biodiversity. Policymakers must set the framework to steer these investments, provide results-oriented incentives for action and work towards international harmonisation, in order to avoid displacement between countries due to ambitious national policies.

## Policy recommendations

1. The current scale of biodiversity decline is unsustainable. An urgent and fundamental correction is needed, in order to align economic incentives with biodiversity conservation.
2. Policymakers should remove biodiversity-damaging subsidies and create incentives for economic actors and the financial sector (both private and public) to channel investments into biodiversity protection and conservation.
3. The value of biodiversity is highly context-specific and requires cross-sectoral policy coordination; strengthening ecosystem accounting will provide critical information for policy and investment decisions.

## Societal recommendations

1. Biodiversity underpins and stabilizes the provision of numerous ecosystem services to society, and thus provides society with an insurance against external shocks.
2. Private consumption, as well as household savings- and investment decisions influence the state of biodiversity, and can also support the conservation of biodiversity.
3. Pressure from the electorate should influence policymaking in such a way as to realign economic incentives, in order to reflect the value of biodiversity to society as a whole.

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# Glossary

**Where possible, the explanations of the Intergovernmental Panel on Climate Change (IPCC), the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and the Convention on Biological Diversity (CBD) have been used for the following terms.**

**Action programme "Natural Climate Protection"**
An action programme proposed by the German political party BÜNDNIS 90/DIE GRÜNEN in 2021, which explicitly aims to protect peatlands and floodplains, forests and soils, as these systems fulfil relevant climate protection functions (e. g. carbon storage). The renaturation of the above-mentioned areas is also intended to strengthen local biodiversity.

**Benthos**
The totality of all organisms living in the bottom zone of a water body.

**Biodiversity offsets**
Compensatory measures for unavoidable (or irreducible) sources of impact on biodiversity and ecosystem services. They lead to measurable results in the enhancement of nature and biodiversity.

**Bioeconomy**
The production, development and use of biological resources, processes and systems to provide products, processes and services in all economic sectors within the framework of a sustainable economic system. It thus holds the potential for sustainable solutions that conserve resources and simultaneously create wealth.

**Biocenosis**
A community of living organisms within a delimited habitat (biotope). Biocenosis and biotope together form an ecosystem.

**Change agents**
Consulting experts who steer and push for constructive clarification in decision-making and conflict situations, as well as innovations and changes in organisational, social, political or technological disciplines.

**Citizen science**
An approach in which scientific knowledge is generated by individuals who are not full-time professionals in the respective science, with or without the involvement of full-time researchers.

**$CO_2$ equivalents**
A unit of measurement used to standardise the climate impact of different greenhouse gases. Emissions of greenhouse gases other than carbon dioxide are converted into $CO_2$ equivalents ($CO_2$=1) according to their global warming potential, for the purpose of improved comparability.

**Digital sequence data (also Digital sequence information, DSI)**
The digital result of the molecular biological decoding (sequencing) of genomes or proteins. Thus, the information about the molecular composition of genetic resources.

**eDNA (Environmental DNA)**
Traces of free DNA that organisms release into the environment and that can be detected using environmental samples. Living organisms release DNA in the form of mucus, scales, fur or cell remnants, among other things.

**Intervention compensation regulation**
An instrument of nature conservation law for the enforcement of nature conservation concerns in so-called "normal landscapes". The aim is to secure and maintain the functional capacity of the natural balance and the landscape even outside of special protection areas.

**Eutrophication**
An accumulation of nutrients in ecosystems caused by human activities. In water bodies, this causes accelerated growth of unicellular algae. The consequences include: e. g. toxic algal blooms, a decrease in water quality and water oxygen content, death of flora and fauna.

**Genetic sequence**
The sequence of genetic building blocks (bases) that compose a gene.

**Gene expression**
A process in which the genetic information of a gene is converted into a gene product (for example, a protein or RNA molecule) and thereby appears.

**Genome, metagenome and genome sequence**
The genome is the entire genetic material of a living being. A metagenome is the totality of the genomic information of the microorganisms of a habitat at the time of the study. A genome sequence contains the totality of the genetic information of a living being.

# Glossary

**Gradient (ecological)**
The gradual change of an environmental factor (temperature, light, humidity). It is often of interest how certain components, e.g. the species composition, of an ecosystem behave as a function of a gradient.

**Holobiont, holobiontic**
A unit consisting of a host and many other species that live in (or around) it and together form a closed biological system. Humans, for example, are holobionts because they interact closely with many microorganisms (in the gut, on the skin).

**Intensive and extensive agriculture**
Intensive (also referred to as conventional or industrial) agriculture aims to maximise the yield per unit of agricultural land. In contrast, the more ecological and environmentally friendly "extensive" agriculture is characterised by a low input of capital and labour (e. g. fertilisers, pesticides, machinery) in relation to the area. The yields per unit of land are lower than in intensive agriculture.

**In-situ-data**
Observational data based on measurements taken on-site. Examples of this include surveys of mountains, seabeds or river flows.

**Invasive species**
Species whose introduction by human activity outside their natural range threatens biodiversity, food security, human health or welfare.

**Cascading effects**
A step-like effect, similar to the domino effect. The triggering is followed inexorably by a series of effects.

**Tipping points**
A level of change in system properties beyond which a system reorganises – often abruptly – and does not return to its original state, even if the drivers of change are dismantled. In relation to the climate system, this term refers to a critical threshold of transition for the global or regional climate from one stable state to a new stable state. The tipping point event may be irreversible.

**Climate stabilis ation areas (CSAs)**
Areas that store enormous reserves of carbon and other greenhouse gases, and whose protection thus plays a major role in stabilising the climate. In line with the Paris Climate Agreement, those areas would focus on habitats such as mangroves, the tundra, other peatlands, and boreal forests and tropical rainforests.

**Climate-resilient forests**
Climate resilience describes the ability of an ecosystem to adapt its structures to climate change in the long term. Climate-resilient forests consist of tree species with different forest-geographic and climatic origins, which increases the potential to adapt to changing climatic conditions.

**Coherence**
An inner or outer connection, or cohesion of something.

**Leakage**
In the case of carbon leakage, for example, companies relocate their production to other countries where emissions regulations are less strict. Thus, greenhouse gas emissions may decrease in one country but increase in another.

**Megafauna**
The proportion of fauna (animals) of a region, habitat or period that constitutes the physically largest organisms weighing more than 45 kg.

**Meta-ecosystems**
A variety of ecosystems connected by spatial flows of energy, materials and organisms across ecosystem boundaries.

**Microbiome**
Totality of all microorganisms (bacteria, fungi, viruses) that colonise humans or other living organisms.

**Molecular high throughput method**
A method with which molecular substances – such as DNA, RNA, proteins and metabolites from biological samples – can be comprehensively examined in a short time in a largely automated process.

**Mutualism, mutualistic symbiosis**
A form of interrelationship between species-different living beings in which all individuals involved derive a benefit from the structure or way of life, respectively.

**Ecosystem functions**
The flow of energy and materials through living and inanimate components of an ecosystem. Ecosystem functions are many processes and functions of an ecosystem, such as biomass production, nutrient cycling, water dynamics and heat transfer.

**Ecosystem accounting**
Ecosystem accounting is a self-contained approach to valuing the environment by measuring ecosystems and the services provided by ecosystems for economic- and other human activities. This basis on the benefits of ecosystems for humans should enable decision-makers in politics and society to adequately consider the services rendered by the environment.

**Ecosystem health**
Ecosystem health is defined as the state of an ecosystem when it is stable and sustainable, i.e. when it is active, maintains its organisation and autonomy over time, and is resilient to stress.

**Ecosystem services**
The benefits that people derive from ecosystems. This can be of monetary or non-monetary value to individuals or society. Ecosystem services are divided into supporting, regulating, provisioning and cultural services. Examples include regulating the climate, providing food, water, building materials and pollinating crops.

**Open science**
This term bundles strategies and procedures that aim to consistently use the opportunities of digitisation to make all components of the scientific process openly accessible, comprehensible and reusable via the internet.

**Nature-based solutions**
Measures to protect, sustainably manage and restore natural (or modified) ecosystems that can address societal challenges in an effective and adaptive manner, while serving the purposes of human well-being and biodiversity.

**Natural capital**
Natural capital describes the world's stock of natural resources, which includes minerals, soil, air, water and all living things in the biosphere. Natural capital provides valuable goods and ecosystem services that make human life possible.

**One Health**
The term stands for a holistic, interdisciplinary approach to health, based on the recognition that human health is closely linked to the health of plants, animals and the environment, and the healthy balance of their impact on the ecosystems they share.

**Ecological resilience**
The ability of an ecosystem to withstand a certain level of stress without significantly altering its structure, organisation, function and identity. Ecological resilience is primarily determined by the resistance and resilience properties of a system.

**Ecological footprint**
A sustainability indicator that describes how much of the Earth's surface a person needs to meet their resource requirements (raw materials and energy). Factors that are incorporated into the calculation include the origin and type of food consumed, the means of transport used or the production conditions of consumer goods.

**Spillover events**
This describes the point in time when a virus has overcome the many naturally occurring barriers and has been transmitted from one species to another, i.e. has "jumped over".

**Planetary health**
That of human civilisation, and the state of the natural systems on which it depends.

**Primary data**
Primary data is based on a survey, observation, measurement or other type of direct data collection. Therefore, it enables direct reference to the object of study, as well as extensive evaluations. This contrasts with the derived secondary data (processed data).

**Primary pandemic prevention**
Preventive measures that minimise the risk of pandemic outbreak and spread. Primary pandemic prevention includes measures such as more effective monitoring of a pathogen's spread, better regulation of the wildlife trade and a significant reduction in deforestation.

# Glossary

**Primary production**
The biomass produced by primary producers such as plants, algae and photosynthetic bacteria.

**Primary forest (primeval forest)**
Forest that is not been (or only slightly) touched by human influence.

**Renaturation**
All intentional activities that initiate or accelerate the recovery of an ecosystem from a degraded to a healthy state. Often, the active restoration of landscapes or their individual elements to as close to their natural state as possible is also the intended meaning.

**Repository**
A document server operated at universities or research institutions on which scientific materials are archived and made accessible worldwide and free of charge.

**Resilience (ecological)**
The regenerative and adaptive capacity of an ecosystem that is exposed to stress, disturbances or other external influences.

**Resistance (ecological)**
The resistance capacity of an ecosystem to stress, disturbance or other external influences. Together with resilience, resistance determines the ecological durability of a system.

**Secondary forest**
Forest that forms after the destruction of the original primary forest, e. g. through road construction, logging or slash-and-burn, and whose composition often consists of fast-growing species that differ from the primary forest.

**Stratified biodiversity monitoring**
A form of monitoring in which the monitoring intensity varies depending on the spatial and temporal level. It is often used when detailed monitoring is not possible for time or financial reasons.

**Taxa (singular: taxon)**
A group of living organisms that form a unit within biological systematics on the basis of certain criteria. Examples of taxa are species, genera, families, classes.

**Telecoupling**
A process that connects distant systems via networks and streams. Examples include trade, migration, tourism or technology transfer. This can include raw materials or energy, as well as people, information or technology. Telecoupling thus describes the fact that human-induced processes in one part of the world affect a distant part (or parts) of the rest of the world in a certain way.

**Animal pathogens**
Organisms capable of causing disease in animals.

**Vector-borne diseases**
Diseases transmitted by vector organisms. A vector is a living organism that transmits pathogens from an infected animal (e. g. mosquitoes, ticks) to a human or another animal. Many vector-borne diseases are zoonoses.

**Zoonoses**
These are infectious diseases that can be caused by bacteria, parasites, fungi, animal proteins or viruses and can be transmitted reciprocally between animals and humans.

# References

## Foreword


1. António Guterres (2020). Speech: The state of the planet, 2.12.2020, Columbia University, (https://www.un.org/sites/un2.un.org/files/sgspeech-the-state-of-planet.pdf) Last accessed on: 1.3.22
2. IPBES (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany
3. Secretariat of the Convention on Biological Diversity (2020) Global Biodiversity Outlook 5 – Summary for Policy Makers. Montréal. ISBN:9789292256883.
4. Pörtner, H.-O. et al. (2021). Scientific outcome of the IPBES-IPCC co-sponsored workshop on biodiversity and climate change. doi:10.5281/zenodo.5101125.
5. Helmholtz-Zentrum für Umweltforschung – UFZ (2021), Biodiversität und Klimawandel, Kurzfassung der wissenschaftlichen Ergebnisse, (Deutsch) (www.ufz.de/export/data/2/254782_Workshop-Bericht_FINAL_1.pdf) Last accessed on: 1.3.22
6. IPCC (2022). Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge University Press)
7. Convention on Biological Diversity (2010). Strategic Plan for Biodiversity 2011-2020, including Aichi Biodiversity Targets. (https://www.cbd.int/sp/) Last accessed on: 1.3.22
8. United Nations (2015). Sustainable Development Goals (SDGs) (https://sdgs.un.org/goals) Last accessed on: 1.3.22
9. Europäische Kommission (2021). Generaldirektion Umwelt, EU biodiversity strategy for 2030: bringing nature back into our lives. doi:10.2779/048
10. BMUB (2007), Nationale Strategie zur biologischen Vielfalt. (https://www.bmuv.de/fileadmin/Daten_BMU/Pools/Broschueren/nationale_strategie_biologische_vielfalt_2015_bf.pdf) Last accessed on: 2.3.22


## 1 Achieving climate and biodiversity protection together


1. Pörtner et al. (2021). Scientific outcome of the IPBES-IPCC co-sponsored workshop on biodiversity and climate change. (IPBES secretariat, Bonn, Germany) doi:10.5281/zenodo.5101125
2. Smith et al. (2021). How do we best synergize climate mitigation actions to co-benefit biodiversity? Glob Chang Biol. doi:10.1111/gcb.16056
3. Shin et al. (2022). Actions to halt biodiversity loss generally benefit the climate. Global Change Biology. doi:10.1111/gcb.16109
4. Gatti et al. (2021). Amazonia as a carbon source linked to deforestation and climate change. Nature. doi:10.1038/s41586-021-03629-6
5. IPBES (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. 56 pages (IPBES secretariat, Bonn, Germany).
6. Dinerstein et al. (2019). A Global Deal For Nature: Guiding principles, milestones, and targets. Science Advances. doi:10.1126/sciadv.aaw2869
7. Hannah et al. (2020). 30% land conservation and climate action reduces tropical extinction risk by more than 50%. Ecography. doi:10.1111/ecog.05166
8. Strassburg Bernardo (2021). A Decade for restoring Earth. Science. doi:10.1126/science.abm6556
9. Sala et al. (2021). Protecting the global ocean for biodiversity, food and climate. Nature. doi:10.1038/s41586-021-03371-z
10. Gerling & Wätzold (2021). An economic evaluation framework for land-use-based conservation policy instruments in a changing climate. Conserv Biol. doi:10.1111/cobi.13631
11. Arneth et al. (2020). Post-2020 biodiversity targets need to embrace climate change. Proceedings of the National Academy of Sciences. doi:10.1073/pnas.2009584117
12. Kehoe et al. (2020). Inclusion, Transparency, and Enforcement: How the EU-Mercosur Trade Agreement Fails the Sustainability Test. One Earth. doi:10.1016/j.oneear.2020.08.013
13. Getirana et al. (2021). Brazil is in water crisis — it needs a drought plan. Nature. doi:10.1038/d41586-021-03625-w
14. Wende et al. (2018). Biodiversity Offsets. European Perspectives on No Net Loss of Biodiversity and Ecosystem Services. XII, 252 (Springer Nature).
15. Arneth et al. (2019). Framing and Context. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. (IPCC)
16. Bullock et al. (2020). Satellite-based estimates reveal widespread forest degradation in the Amazon. Global Change Biology. doi:10.1111/gcb.15029
17. Anderegg William et al. (2020). Climate-driven risks to the climate mitigation potential of forests. Science. doi:10.1126/science.aaz7005
18. Schuldt et al. (2020). A first assessment of the impact of the extreme 2018 summer drought on Central European forests. Basic and Applied Ecology. doi:https://doi.org/10.1016/j.baae.2020.04.003
19. Tanneberger et al. (2021). Towards net zero $CO_2$ in 2050: An emission reduction pathway for organic soils in Germany. Mires and Peat. doi:10.19189/MaP.2020.SNPG.StA.1951
20. Wichmann et al. (2020). Paludiculture on former bog grassland: Profitability of Sphagnum farming in North West Germany. Mires and Peat. doi:10.19189/MaP.2019.SNPG.StA.1768
21. Atwood et al. (2020). Global Patterns in Marine Sediment Carbon Stocks. Frontiers in Marine Science. doi: 10.3389/fmars.2020.00165
22. Savoca et al. (2021). Baleen whale prey consumption based on high-resolution foraging measurements. Nature. doi:10.1038/s41586-021-03991-5
23. Rajão et al. (2020). The rotten apples of Brazil's agribusiness. Science. doi:10.1126/science.aba6646
24. Cook-Patton et al. (2021). Protect, manage and then restore lands for climate mitigation. Nat. Clim. Chang. doi:10.1038/s41558-021-01198-0
25. EU Commission (2020). Communication from the commission to the european parliament, the council, the european economic and social committee and the committee of the regions - EU Biodiversity Strategy for 2030, Bringing nature back into our lives.
26. Wende et al. (2020). Evaluating municipal landscape plans and their influence on selected aspects of landscape development – An empirical study from Germany. Land Use Policy. doi:10.1016/j.landusepol.2020.104855
27. Friedlingstein et al. (2021). Global Carbon Budget 2021. Earth Syst. Sci. Data Discuss. doi:10.5194/essd-2021-386


## 2 Strengthening planetary health


1. Marselle et al. (2021). Pathways linking biodiversity to human health: A conceptual framework. Environment International. doi:10.1016/j.envint.2021.106420
2. Bernstein et al. (2022). The costs and benefits of primary prevention of zoonotic pandemics. Sci. Adv. doi:10.1126/sciadv.abl4183
3. Willett et al. (2019). Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet. doi:10.1016/S0140-6736(18)31788-4
4. Volta et al. (2021). Co-benefits of changing diet. A modelling assessment at the regional scale integrating social acceptability, environmental and health impacts. Science of The Total Environment. doi:10.1016/j.scitotenv.2020.143708
5. Ebi et al. (2020). Transdisciplinary Research Priorities for Human and Planetary Health in the Context of the 2030 Agenda for Sustainable Development. International Journal of Environmental Research and Public Health. doi:10.3390/ijerph17238890
6. Delabre et al. (2021). Actions on sustainable food production and consumption for the post-2020 global biodiversity framework. Science Advances. doi:10.1126/sciadv.abc8259
7. Howes et al. (2020). Molecules from nature: Reconciling biodiversity conservation and global healthcare imperatives for sustainable use of medicinal plants and fungi. PLANTS, PEOPLE, PLANET. doi:10.1002/ppp3.10138

# References


8. Garcia-Candela et al. (2021). Antiviral activity of the sea cucumber tegument extract (Pattalus mollis) on human rotavirus A (RVA). Nat Prod Res. doi:10.1080/14786419.2019.1611807
9. Newman & Cragg (2020). Natural Products as Sources of New Drugs over the Nearly Four Decades from 01/1981 to 09/2019. J. Nat. Prod. doi:10.1021/acs.jnatprod.9b01285
10. Roe (2019). Biodiversity loss—more than an environmental emergency. The Lancet Planetary Health. doi:10.1016/S2542-5196(19)30113-5
11 Marselle et al. (2019). Biodiversity and Health in the Face of Climate Change. doi:10.1007/978-3-030-02318-8
12. Cox et al. (2017). Doses of Neighborhood Nature: The Benefits for Mental Health of Living with Nature. BioScience. doi:10.1093/biosci/biw173
13. Methorst et al. (2021). The importance of species diversity for human well-being in Europe. Ecological Economics. doi:10.1016/j.ecolecon.2020.106917
14. Ohly et al. (2016). Attention Restoration Theory: A systematic review of the attention restoration potential of exposure to natural environments. J Toxicol Environ Health B Crit Rev. doi:10.1080/10937404.2016.1196155
15. Venter et al. (2020). Urban nature in a time of crisis: recreational use of green space increases during the COVID-19 outbreak in Oslo, Norway. Environ. Res. Lett. doi:10.1088/1748-9326/abb396
16. Soga & Gaston (2016). Extinction of experience: the loss of human–nature interactions. Frontiers in Ecology and the Environment. doi:10.1002/fee.1225
17. Weiss & Sankaran (2022). Emergence of epidemic diseases: zoonoses and other origins. F1000Prime Rep. doi:10.12703/r/11-2
18. Plowright et al. (2021). Land use-induced spillover: a call to action to safeguard environmental, animal, and human health. The Lancet Planetary Health. doi:10.1016/S2542-5196(21)00031-0
19. Johnson et al. (2020). Global shifts in mammalian population trends reveal key predictors of virus spillover risk. Proc Biol Sci. doi:10.1098/rspb.2019.2736
20. Morand & Lajaunie (2021). Outbreaks of Vector-Borne and Zoonotic Diseases Are Associated With Changes in Forest Cover and Oil Palm Expansion at Global Scale. Frontiers in Veterinary Science. doi:10.3389/fvets.2021.661063
21. Huong et al. (2020). Coronavirus testing indicates transmission risk increases along wildlife supply chains for human consumption in Viet Nam, 2013-2014. PLOS ONE. doi:10.1371/journal.pone.0237129
22. Machalaba et al. (2021). Gaps in health security related to wildlife and environment affecting pandemic prevention and preparedness, 2007–2020. Bull. World Health Organ. doi:10.2471/BLT.20.272690
23. World Organisation for Animal Health (2021): OIE Wildlife Health Framework https://www.oie.int/fileadmin/Home/eng/Internationa_Standard_Setting/docs/pdf/WGWildlife/A_Wildlifehealth_conceptnote.pdf. Last accessed on: 2.3.22
24. Hale et al. (2022). SARS-CoV-2 infection in free-ranging white-tailed deer. Nature. doi:10.1038/s41586-021-04353-x
25. Dobson et al. (2020). Ecology and economics for pandemic prevention: Investments to prevent tropical deforestation and to limit wildlife trade will protect against future zoonosis outbreaks. Science. doi:10.1126/science.abc3189
26. van Bruggen et al. (2019). One Health - Cycling of diverse microbial communities as a connecting force for soil, plant, animal, human and ecosystem health. Sci Total Environ. doi:10.1016/j.scitotenv.2019.02.091
27. Pörtner et al. (2021). Scientific outcome of the IPBES-IPCC co-sponsored workshop on biodiversity and climate change. (IPBES secretariat, Bonn, Germany). doi:10.5281/zenodo.5101125
28. Zanten et al. (2016). Opinion paper: The role of livestock in a sustainable diet: a land-use perspective. Animal. doi:10.1017/S1751731115002694
29. Ekor (2014). The growing use of herbal medicines: issues relating to adverse reactions and challenges in monitoring safety. Frontiers in Pharmacology. doi:10.3389/fphar.2013.00177.
30. Fuller et al. (2007). Psychological benefits of greenspace increase with biodiversity. Biology Letters. doi:10.1098/rsbl.2007.0149
31. Dallimer et al. (2012). Biodiversity and the Feel-Good Factor: Understanding Associations between Self-Reported Human Well-being and Species Richness. BioScience. doi:10.1525/bio.2012.62.1.9
32. Marselle et al. (2020). Urban street tree biodiversity and antidepressant prescriptions. Sci Rep. doi:10.1038/s41598-020-79924-5
33. Kabisch, N., Korn, H., Stadler, J. & Bonn, A. (2017) Nature-based solutions to climate change adaptation in urban areas - Linkages of science, policy and practice. Springer, Cham, Switzerland. (https://www.springer.com/de/book/9783319537504). Last accessed on: 2.3.22
34. Hobbie & Grimm (2020). Nature-based approaches to managing climate change impacts in cities. Philosophical Transactions of the Royal Society B: Biological Sciences. doi:10.1098/rstb.2019.0124
35. Carroll et al. (2018). The Global Virome Project. Science. doi:10.1126/science.aap7463
36. Jones et al. (2008). Global trends in emerging infectious diseases. Nature. doi:10.1038/nature06536
37. Andersen et al. (2020). The proximal origin of SARS-CoV-2. Nat Med. doi:10.1038/s41591-020-0820-9
38. Taylor et al. (2001). Risk factors for human disease emergence. Philos Trans R Soc Lond B Biol Sci. doi:10.1098/rstb.2001.0888
39. Schmeller et al. (2020). Biodiversity loss, emerging pathogens and human health risks. Biodivers Conserv. doi:10.1007/s10531-020-02021-6
40. Patz et al. (2004). Unhealthy Landscapes: Policy Recommendations on Land Use Change and Infectious Disease Emergence. Environ Health Perspect. doi:10.1289/ehp.6877
41. Wolfe et al. (2007). Origins of major human infectious diseases. Nature. doi:10.1038/nature05775
42. Reddy & Saier (2020). The Causal Relationship between Eating Animals and Viral Epidemics. Microb Physiol. doi:10.1159/000511192
43. Andleeb et al. (2020). Chapter 18 - Environmental and public health effects of antibiotics and AMR/ARGs. in Antibiotics and Antimicrobial Resistance Genes in the Environment doi:10.1016/B978-0-12-818882-8.00018-8
44. Graham et al. (2019). Complexities in understanding antimicrobial resistance across domesticated animal, human, and environmental systems. Ann N Y Acad Sci. doi:10.1111/nyas.14036
45. Dhingra et al. (2020). Microbial Resistance Movements: An Overview of Global Public Health Threats Posed by Antimicrobial Resistance, and How Best to Counter. Frontiers in Public Health. doi:10.3389/fpubh.2020.535668
46. Reaser et al. (2022). Fostering landscape immunity to protect human health: A science-based rationale for shifting conservation policy paradigms. Conservation Letters. doi:10.1111/conl.12869
47. White et al. (2019). Spending at least 120 minutes a week in nature is associated with good health and wellbeing. Sci Rep. doi:10.1038/s41598-019-44097-3


## 3 Considering hidden biodiversity


1. Delso et al. (2021). Protected area networks do not represent unseen biodiversity. Sci Rep. doi:10.1038/s41598-021-91651-z
2. Acreman et al. (2020). Protected areas and freshwater biodiversity: a novel systematic review distils eight lessons for effective conservation. Conservation Letters. doi:10.1111/conl.12684
3. He et al. (2021). Impacts of loss of free-flowing rivers on global freshwater megafauna. Biological Conservation. doi:10.1016/j.biocon.2021.109335
4. Tickner et al. (2020). Bending the Curve of Global Freshwater Biodiversity Loss: An Emergency Recovery Plan. BioScience. doi:10.1093/biosci/biaa002
5. Maasri et al. (2022). A global agenda for advancing freshwater biodiversity research. Ecol Lett. doi:10.1111/ele.13931
6. O'Connor (2021). Microbiology challenges and opportunities in the circular economy. Microbiology (Reading). doi:10.1099/mic.0.001026
7. Guerra et al. (2021). Tracking, targeting, and conserving soil biodiversity. Science. doi:10.1126/science.abd7926
8. Bennett et al. (2020). Resistance of soil biota and plant growth to disturbance increases with plant diversity. Ecology Letters. doi:10.1111/ele.13408
9. Hölker et al. (2021). 11 Pressing Research Questions on How Light Pollution Affects Biodiversity. Frontiers in Ecology and Evolution. doi:10.3389/fevo.2021.767177

10. Schroer et al. (2020). Working with Inadequate Tools: Legislative Shortcomings in Protection against Ecological Effects of Artificial Light at Night. Sustainability. doi:10.3390/su12062551
11. Sordello et al. (2022). A plea for a worldwide development of dark infrastructure for biodiversity – Practical examples and ways to go forward. Landscape and Urban Planning. doi:10.1016/j.landurbplan.2021.104332
12. Vilà et al. (2021). Viewing Emerging Human Infectious Epidemics through the Lens of Invasion Biology. BioScience. doi:10.1093/biosci/biab047
13. Pyšek et al. (2020). Scientists' warning on invasive alien species. Biological Reviews. doi:10.1111/brv.12627
14. Pergl et al. (2020). Need for routine tracking of biological invasions. Conservation Biology. doi:10.1111/cobi.13445
15. Wei et al. (2020). Long-term urbanization impacts the eastern golden frog (Pelophylax plancyi) in Shanghai City: Demographic history, genetic structure, and implications for amphibian conservation in intensively urbanizing environments. Evol Appl. doi:10.1111/eva.13156
16. Urban et al. (2022). Coding for Life: Designing a Platform for Projecting and Protecting Global Biodiversity. BioScience. doi:10.1093/biosci/biab099
17. Urban et al. (2020). Evolutionary origins for ecological patterns in space. PNAS. doi:10.1073/pnas.1918960117
18. Díaz et al. (2020). Set ambitious goals for biodiversity and sustainability. Sciece. doi:10.1126/science.abe1530
19. Otto et al. (2021). The origins and potential future of SARS-CoV-2 variants of concern in the evolving COVID-19 pandemic. Curr Biol. doi:10.1016/j.cub.2021.06.049
20. Manuel et al. (2022). Strengthening Public Health Surveillance Through Wastewater Testing: An Essential Investment for the COVID-19 Pandemic and Future Health Threats. doi:10.1596/36852
21. Hinz et al. (2022). SARS-CoV-2 detection from the built environment and wastewater and its use for hospital surveillance. FACETS. doi:10.1139/facets-2021-0139
22. WWF Living Planet Report 2020. WWF Deutschlan. (https://www.wwf.de/living-planet-report) Last accessed on: 2.3.22
23. Veresoglou et al. (2015). Extinction risk of soil biota. Nat Commun. doi:10.1038/ncomms9862
24. Maaroufi & De Long (2020). Global Change Impacts on Forest Soils: Linkage Between Soil Biota and Carbon-Nitrogen-Phosphorus Stoichiometry. Frontiers in Forests and Global Change. doi: 10.3389/ffgc.2020.00016
25. Geisen et al. (2019). Challenges and Opportunities for Soil Biodiversity in the Anthropocene. Current Biology. doi:10.1016/j.cub.2019.08.007
26. Kyba et al. (2017). Artificially lit surface of Earth at night increasing in radiance and extent. Sci. Adv. doi:10.1126/sciadv.1701528
27. CCA, Council of Canadian Academies Report (2019). When Antibiotics Fail: The Expert Panel on the Potential Socio-Economic Impacts of Antimicrobial Resistance in Canada. (https://cca-reports.ca/wp-content/uploads/2018/10/When-Antibiotics-Fail-1.pdf) Last accessed on: 2.3.22
28. Singh et al. (2021). Global patterns in genomic diversity underpinning the evolution of insecticide resistance in the aphid crop pest Myzus persicae. Commun Biol. doi:10.1038/s42003-021-02373-x
29. IPBES (2020). Workshop Report on Biodiversity and Pandemics of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES). doi:10.5281/ZENODO.4147317


## 4 Promoting biocultural habitats


1. Maffi (2001). On biocultural diversity: linking language, knowledge, and the environment. (Washington, Smithsonian Institution Press), ISBN: 978-1-56098-905-9 978-1-56098-930-1
2. Bridgewater & Rotherham (2019). A critical perspective on the concept of biocultural diversity and its emerging role in nature and heritage conservation. People and Nature. doi:10.1002/pan3.10040
3. Gorenflo et al. (2012). Co-occurrence of linguistic and biological diversity in biodiversity hotspots and high biodiversity wilderness areas. PNAS. doi:10.1073/pnas.1117511109
4. Harmon & Loh (2018). Congruence Between Species and Language Diversity. in: The Oxford handbook of endangered languages. (Oxford, Oxford University Press), ISBN: 9780190610029, doi:10.1093/oxfordhb/9780190610029.013.31
5. Rapport & Singh (2006). An EcoHealth-based framework for State of Environment Reporting. Ecological Indicators. doi:10.1016/j.ecolind.2005.05.003
6. McElwee et al. (2020). Working with Indigenous and local knowledge (ILK) in large-scale ecological assessments: Reviewing the experience of the IPBES Global Assessment. Journal of Applied Ecology. doi:10.1111/1365-2664.13705
7. Mann et al. (2021). Assessing forest governance innovations in Europe: Needs, challenges and ways forward for sustainable forest ecosystem service provision. Ecosystem Services. doi:10.1016/j.ecoser.2021.101384
8. Hill et al. (2020). Working with Indigenous, local and scientific knowledge in assessments of nature and nature's linkages with people. Current Opinion in Environmental Sustainability. doi:10.1016/j.cosust.2019.12.006
9. Reyes-García et al. (2022). Recognizing Indigenous peoples' and local communities' rights and agency in the post-2020 Biodiversity Agenda. Ambio. doi:10.1007/s13280-021-01561-7
10. Cámara-Leret & Bascompte (2021). Language extinction triggers the loss of unique medicinal knowledge. PNAS. doi:10.1073/pnas.2103683118
11. Kik et al. (2021). Language and ethnobiological skills decline precipitously in Papua New Guinea, the world's most linguistically diverse nation. PNAS. doi:10.1073/pnas.2100096118
12. Harrison (2007). When languages die: the extinction of the world's languages and the erosion of human knowledge. (Oxford, Oxford University Press), doi:10.1093/acprof:oso/9780195181920.001.0001
13. Campbell & Belew (2018). Cataloguing the world's endangered languages. (New York, Routledge), ISBN: ISBN 9780367580902
14. IUCN Red List 2021-3. (https://www.iucnredlist.org) Last accessed on: 2.3.22
15. Bromham et al. (2022). Global predictors of language endangerment and the future of linguistic diversity. Nat Ecol Evol. doi:10.1038/s41559-021-01604-y
16. Díaz et al. (2019). Pervasive human-driven decline of life on Earth points to the need for transformative change. Science. doi:10.1126/science.aax3100


## 5 Using forests sustainably


1. Mann et al. (2021). Assessing forest governance innovations in Europe: Needs, challenges and ways forward for sustainable forest ecosystem service provision. Ecosystem Services. doi:10.1016/j.ecoser.2021.101384
2. Forzieri et al. (2021). Emergent vulnerability to climate-driven disturbances in European forests. Nature Communications. doi:10.1038/s41467-021-21399-7
3. Senf & Seidl (2021). Mapping the forest disturbance regimes of Europe. Nature Sustainability. doi:10.1038/s41893-020-00609-y
4. Brun et al. (2020). Large-scale early-wilting response of Central European forests to the 2018 extreme drought. Global Change Biology. doi:https://doi.org/10.1111/gcb.15360
5. Senf & Seidl (2021). Persistent impacts of the 2018 drought on forest disturbance regimes in Europe. Biogeosciences. doi:10.5194/bg-18-5223-2021
6. Schuldt et al. (2020). A first assessment of the impact of the extreme 2018 summer drought on Central European forests. Basic and Applied Ecology. doi:10.1016/j.baae.2020.04.003
7. Anderegg William et al. (2020). Climate-driven risks to the climate mitigation potential of forests. Science. doi:10.1126/science.aaz7005
8. Schroeder et al. (2021). Oaks as Beacons of Hope for Threatened Mixed Forests in Central Europe. Frontiers in Forests and Global Change. doi:10.3389/ffgc.2021.670797
9. Betts et al. (2021). Producing wood at least cost to biodiversity: integrating Triad and sharing–sparing approaches to inform forest landscape management. Biological Reviews. doi:10.1111/brv.12703

# References


10. Schulze et al. (2020). The Impact of Accounting for Future Wood Production in Global Vertebrate Biodiversity Assessments. Environ Manage. doi:10.1007/s00267-020-01322-4
11. Kirpotin et al. (2021). Impacts of environmental change on biodiversity and vegetation dynamics in Siberia. Ambio. doi:10.1007/s13280-021-01570-6
12. de la Sancha et al. (2021). The disappearing Dry Chaco, one of the last dry forest systems on earth. Landscape Ecology. doi:10.1007/s10980-021-01291-x
13. Maia et al. (2020). The carbon sink of tropical seasonal forests in southeastern Brazil can be under threat. Science Advances. doi:10.1126/sciadv.abd4548
14. Statisches Bundesamt (2022), D. Pressemitteilung Nr. N 041 vom 27. Juli 2020. (https://www.destatis.de/DE/Presse/Pressemitteilungen/2020/07/PD20_N041_412.html) Last accessed on: 2.3.22
15. Harris et al. (2021). Global maps of twenty-first century forest carbon fluxes. Nature Climate Change. doi:10.1038/s41558-020-00976-6


## 6 Transforming agriculture


1. Beckmann et al. (2019). Conventional land-use intensification reduces species richness and increases production: A global meta-analysis. Global Change Biology. doi:10.1111/gcb.14606
2. Schuldt et al. (2019). Multiple plant diversity components drive consumer communities across ecosystems. Nat Commun. doi:10.1038/s41467-019-09448-8
3. Raven & Wagner (2021). Agricultural intensification and climate change are rapidly decreasing insect biodiversity. PNAS. doi:10.1073/pnas.2002548117
4. Marques et al. (2019). Increasing impacts of land use on biodiversity and carbon sequestration driven by population and economic growth. Nat Ecol Evol. doi:10.1038/s41559-019-0824-3
5. Nicholson et al. (2021). Global relationships between crop diversity and nutritional stability. Nat Commun. doi:10.1038/s41467-021-25615-2
6. Chen et al. (2021). Diversity increases yield but reduces harvest index in crop mixtures. Nat. Plants. doi:10.1038/s41477-021-00948-4
7. Turner et al. (2020). Effects of genomic and functional diversity on stand-level productivity and performance of non-native Arabidopsis. Proceedings of the Royal Society B: Biological Sciences. doi:10.1098/rspb.2020.2041
8. Weisser et al. (2017). Biodiversity effects on ecosystem functioning in a 15-year grassland experiment: Patterns, mechanisms, and open questions. Basic and Applied Ecology. doi:10.1016/j.baae.2017.06.002
9. Furey & Tilman (2021). Plant biodiversity and the regeneration of soil fertility. PNAS. doi:10.1073/pnas.2111321118
10. Egli et al. (2020). Crop asynchrony stabilizes food production. Nature. doi:10.1038/s41586-020-2965-6
11. Cai et al. (2021). Cell-free chemoenzymatic starch synthesis from carbon dioxide. Science. doi:10.1126/science.abh4049
12. Eldridge et al. (2020). Getting to the roots of aeroponic indoor farming. New Phytologist. doi:10.1111/nph.16780
13. Asseng et al. (2020). Wheat yield potential in controlled-environment vertical farms. PNAS. doi:10.1073/pnas.2002655117
14. OECD Incentive Measures for Biodiversity (https://www.oecd.org/env/resources/incentive-measures-for-biodiversity.htm). Last accessed on: 25.2.22
15. Maas et al. (2021). Divergent farmer and scientist perceptions of agricultural biodiversity, ecosystem services and decision-making. Biological Conservation. doi:10.1016/j.biocon.2021.109065
16. Seppelt et al. (2020). Deciphering the Biodiversity–Production Mutualism in the Global Food Security Debate. Trends in Ecology & Evolution. doi:10.1016/j.tree.2020.06.012
17. Arneth et al. (2020). Post-2020 biodiversity targets need to embrace climate change. Proceedings of the National Academy of Sciences. doi:10.1073/pnas.2009584117
18. Eichenberg et al. (2021). Widespread decline in Central European plant diversity across six decades. Global Change Biology. doi:10.1111/gcb.15447
19. Lowder et al. (2021). Which farms feed the world and has farmland become more concentrated? World Development. doi:10.1016/j.worlddev.2021.105455


## 7 Protecting land and resources


1. 1. UN News. Global perspective Human stories. Access to a healthy environment, declared a human right by UN rights council. (https://news.un.org/en/node/1102582/%20%0D2). Last accessed on: 21.2.22
2. Europäische Kommission (2011). Lebensversicherung und Naturkapital: Eine Biodiversitätsstrategie der EU für das Jahr 2020.
3. Arneth et al. (2021). Biodiversität und Klimawandel. Eine gemeinsame Analyse von Autoren des Weltbiodiversitätsrates IPBES und des Weltklimarates IPCC (Workshop- Bericht). (https://www.ufz.de/export/data/2/254782_Workshop-Bericht_FINAL_1.pdf). Last accessed on: 21.2.22
4. Sukhdev et al. (2014). The Economics of Ecosystems and biodiversity (TEEB): Challenges and Responses, in D. Helm and C. Hepburn (eds), Nature in the Balance: The Economics of Biodiversity. The Economics of Ecosystems and Biodiversity. (Oxford, Oxford University Press)
5. Informationen zum Projekt "Ökosystemleistungen in Stadt-und Regionalplanung - ÖSKKIP". (https://www.öskkip.de/). Last accessed on: 21.2.22
6. Perino et al. Biodiversity post-2020: Closing the gap between global targets and national-level implementation. Conservation Letters. doi:10.1111/conl.12848
7. Brühl et al. (2021). Direct pesticide exposure of insects in nature conservation areas in Germany. Sci Rep. doi:10.1038/s41598-021-03366-w
8. Dinerstein et al. (2019). A Global Deal For Nature: Guiding principles, milestones, and targets. Science Advances. doi:10.1126/sciadv.aaw2869
9. Schütte et al. (2018). Aktivierung nichtnaturschutzrechtlicher Fachplanungsinstrumente und der räumlichen Gesamtplanung zur Umsetzung der Nationalen Biodiversitätsstrategie. Umweltbundesamt. ISSN: 1862-4359
10. Hofreiter & Niebert (2021). Schluss mit 'ja, aber'! Gastbeitrag im klimareporter, 07.07.2021. (https://www.klimareporter.de/energiewende/schluss-mit-ja-aber). Last accessed on: 21.2.22
11. Europäische Kommission (2021). EU biodiversity strategy for 2030 : bringing nature back into our lives. doi:10.10.2779/677548
12. Europäische Kommission (2021). EU-Bodenstrategie für 2030. Die Vorteile gesunder Böden für Menschen, Lebensmittel, Natur und Klima nutzen.
13. Krause et al. (2013). Die Meeresschutzgebiete der deutschen Nordsee – vom Wattenmeer bis in die ausschließliche Wirtschaftszone. Natur und Landschaft 97.1/2022: 2-8; s. auch Managementpläne für die Schutzgebiete der Nord- und Ostsee (https://www.bfn.de/management-1) Last accessed on: 21.2.22
14. von Weizsäcker et al. (2017). Wir sind dran. Club of Rome: Der große Bericht: Was wir ändern müssen, wenn wir bleiben wollen. Eine neue Aufklärung für eine volle Welt. Gütersloher Verlagshaus. ISBN:978-3-579-08693-4
15. Lesch & Kamphausen (2018). Die Menschheit schafft sich ab - Die Erde im Griff des Anthropozän. Knaur TB. ISBN: 978-3-426-78940-7
16. IPCC (2019). Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable management, food security, and greenhouse gas fluxes in terrestrial ecosystems. In press.
17. Projektauftakt „SALBES": Landwirtschaft und Biodiversität – auf der Suche nach dem Gleichgewicht. (https://www.kooperation-international.de/aktuelles/nachrichten/detail/info/projektauftakt-salbes-landwirtschaft-und-biodiversitaet-auf-der-suche-nach-dem-gleichgewicht/). Last accessed on: 21.2.22
18. Agricultural Climate Resilience Enhancement Initiative (ACREI). (https://public.wmo.int/en/projects/agricultural-climate-resilience-enhancement-initiative-acrei-0). Last accessed on: 21.2.22
19. Pörtner, H.-O. et al. (2021). IPBES-IPCC co-sponsored workshop report on biodiversity and climate change. doi:10.5281/ZENODO.4782538

20. „EUKI - Kohlenstoffbindung durch baltische Moorlandwirte", (https://www.succow-stiftung.de/moor-klima/baltikum-euki-kohlenstoffbindung-durch-baltische-moorlandwirte). Last accessed on: 21.2.22
21. Wiedervernässung von Torfmooren in Russland – Verhütung von Bränden und Abmilderung des Klimawandels. (https://www.international-climate-initiative.com/de/details/project/wiedervernaessung-von-torfmooren-in-russland-verhuetung-von-braenden-und-abmilderung-des-klimawandels-11_III_040-117). Last accessed on: 21.2.22
22. Schneidewind (2018). Die große Transformation - Eine Einführung in die Kunst gesellschaftlichen Wandels. FISCHER Taschenbuch. ISBN:978-3-596-70259-6
23. Pörtner (2021). Scientific outcome of the IPBES-IPCC co-sponsored workshop on biodiversity and climate change. (IPBES secretariat, Bonn, Germany) doi:10.5281/zenodo.5101125
24. van der Velde & Leuven (2011). The Special Column of Aquatic Invasive Species Science. Current Zoology. doi:10.1093/czoolo/57.6.816
25. Pestizidatlas 2022: Gifte in der Landwirtschaft. Heinrich-Böll-Stiftung. (https://www.boell.de/de/pestizidatlas). Last accessed on: 21.2.22
26. FAO (2020). State of knowledge of soil biodiversity - Status, challenges and potentialities: Report 2020. doi:10.4060/cb1928en
27. https://www.eea.europa.eu/data-and-maps/indicators/land-take-3/assessment und https://www.eea.europa.eu/data-and-maps/dashboards/land-take-statistics. Last accessed on: Feb 21, 2022

## 8 Expanding transnational infrastructures and education for sustainability

1. Schröter et al. (2018). Interregional flows of ecosystem services: Concepts, typology and four cases. Ecosystem Services. doi:10.1016/j.ecoser.2018.02.003
2. Kehoe et al. (2020). Inclusion, Transparency, and Enforcement: How the EU-Mercosur Trade Agreement Fails the Sustainability Test. One Earth. doi:10.1016/j.oneear.2020.08.013
3. Campagnaro et al. (2019). Half Earth or Whole Earth: What Can Natura 2000 Teach Us? BioScience. doi:10.1093/biosci/biy153
4. Hermoso et al. (2022). The EU Biodiversity Strategy for 2030: Opportunities and challenges on the path towards biodiversity recovery. Environmental Science & Policy. doi:10.1016/j.envsci.2021.10.028
5. Pereira et al. (2022). Europa Biodiversity Observation Network: integrating data streams to support policy. ARPHA Preprints. doi:10.3897/arphapreprints.e81207
6. Moersberger et al. (2021). EuropaBON: User and Policy Needs Assessment. EuropaBON/iDiv. doi:10.3897/rio.coll.145
7. Perino et al. (2021). Biodiversity post-2020: Closing the gap between global targets and national-level implementation. Conservation Letters. doi:10.1111/conl.12848
8. Navarro et al. (2017). Monitoring biodiversity change through effective global coordination. Current Opinion in Environmental Sustainability. doi:10.1016/j.cosust.2018.02.005
9. Hughes et al. (2021). Sampling biases shape our view of the natural world. Ecography. doi:10.1111/ecog.05926
10. Hochkirch et al. (2021). A strategy for the next decade to address data deficiency in neglected biodiversity. Conserv Biol. doi:10.1111/cobi.13589
11. Callaghan et al. (2020). Three Frontiers for the Future of Biodiversity Research Using Citizen Science Data. BioScience. doi:10.1093/biosci/biaa131
12. Kelly et al. (2020). Citizen science and marine conservation: a global review. Philosophical Transactions of the Royal Society B: Biological Sciences. doi:10.1098/rstb.2019.0461
13. Rapacciuolo et al. (2021). Deriving indicators of biodiversity change from unstructured community-contributed data. Oikos. doi:10.1111/oik.08215
14. Richter et al. (2021). Motivation and support services in citizen science insect monitoring: A cross-country study. Biological Conservation. doi:10.1016/j.biocon.2021.109325
15. Bonney et al. (2021). Sea Change: Using Citizen Science to Inform Fisheries Management. BioScience. doi:10.1093/biosci/biab016
16. Sordello et al. (2022). A plea for a worldwide development of dark infrastructure for biodiversity – Practical examples and ways to go forward. Landscape and Urban Planning. doi:10.1016/j.landurbplan.2021.104332
17. Kimic & Ostrysz (2021). Assessment of Blue and Green Infrastructure Solutions in Shaping Urban Public Spaces—Spatial and Functional, Environmental, and Social Aspects. Sustainability. doi:10.3390/su131911041
18. Gao et al. (2020). Change of stream network connectivity and its impact on flood control. Water Science and Engineering. doi:10.1016/j.wse.2020.12.004
19. van Rees et al. (2021). Safeguarding freshwater life beyond 2020: Recommendations for the new global biodiversity framework from the European experience. Conservation Letters. doi:10.1111/conl.12771
20. Pereira et al. (2013). Essential Biodiversity Variables. doi:10.1126/science.1229931

## 9 Ensuring access and open use of research data

1. Calas et al. (2021). Biodiversity: toward better data sharing. ID4D: Sustainable Development News. (https://ideas4development.org/en/biodiversity-toward-better-data-sharing/) Last accessed on: 2.3.22
2. Heberling et al. (2021). Data integration enables global biodiversity synthesis. PNAS. doi:10.1073/pnas.2018093118
3. Lange et al. (2014). Biotic and Abiotic Properties Mediating Plant Diversity Effects on Soil Microbial Communities in an Experimental Grassland. PLoS ONE. doi:10.1371/journal.pone.0096182
4. Mandeville et al. (2021). Open Data Practices among Users of Primary Biodiversity Data. BioScience. doi:10.1093/biosci/biab072
5. Miralles et al. (2020). Repositories for Taxonomic Data: Where We Are and What is Missing. Systematic biology. doi:10.1093/sysbio/syaa026
6. Wührl et al. (2021). DiversityScanner: Robotic discovery of small invertebrates with machine learning methods. doi:10.1101/2021.05.17.444523
7. Ewers-Saucedo et al. Natural history collections recapitulate 200 years of faunal change. Royal Society Open Science. doi:10.1098/rsos.201983
8. Stephenson & Stengel (2020). An inventory of biodiversity data sources for conservation monitoring. PLOS ONE. doi:10.1371/journal.pone.0242923
9. Wetzel et al. (2018). Unlocking biodiversity data: Prioritization and filling the gaps in biodiversity observation data in Europe. Biological Conservation. doi:10.1016/j.biocon.2017.12.024
10. Heinrich et al. (2020). Access and Benefit Sharing Under the Nagoya Protocol—Quo Vadis? Six Latin American Case Studies Assessing Opportunities and Risk. Frontiers in Pharmacology. doi:10.3389/fphar.2020.00765
11. von Wettberg & Khoury (2022). Biodiversity data: The importance of access and the challenges regarding benefit sharing. PLANTS, PEOPLE, PLANET. doi:10.1002/ppp3.10241
12. Arita et al. (2021). The international nucleotide sequence database collaboration. Nucleic Acids Research. doi:10.1093/nar/gkaa967
13. Tian et al. (2021). Designing future crops: challenges and strategies for sustainable agriculture. The Plant Journal. doi:10.1111/tpj.15107
14. FishBase (www.fishbase.de) Last accessed on: 2.3.22
15. Edaphobase (portal.edaphobase.org) Last accessed on: 2.3.22
16. Thonicke et al. (2020). Simulating functional diversity of European natural forests along climatic gradients. Journal of Biogeography. doi:10.1111/jbi.13809
17. Bruelheide et al. (2018). Global trait–environment relationships of plant communities. Nat Ecol Evol. doi:10.1038/s41559-018-0699-8
18. Overmann & Scholz (2017). Microbiological Research Under the Nagoya Protocol: Facts and Fiction. Trends in Microbiology. doi:10.1016/j.tim.2016.11.001
19. Alves et al. (2018). Brazilian legislation on genetic heritage harms Biodiversity Convention goals and threatens basic biology research and education. An. Acad. Bras. Ciênc. doi:10.1590/0001-3765201820180460
20. Pawar (2020). Strict biodiversity laws prevent Indian scientists from sharing new microbes with the world. Science. doi:10.1126/science.abf3547

# References


21. Scholz et al. (2021). Myth-busting the provider-user relationship for digital sequence information. GigaScience. doi:10.1093/gigascience/giab085
22. Nationale Akademie der Wissenschaften Leopoldina (2021). Den offenen Zugang zu digitalen Sequenzinformationen erhalten - multilateraler Vorteilsausgleich und offene Wissenschaft. Halle (Saale), 27pp. ISBN: 978-3-8047-4219-2
23. Global Biodiversity Information Facility (www.gbif.org) Last accessed on: 2.3.22
24. GenBank (www.ncbi.nlm.nih.gov/genbank/statistics/) Last accessed on: 2.3.22
25. TRY-Datenbank (www.try-db.org/TryWeb/Home.php) Last accessed on: 2.3.22


## 10 Setting biodiversity-friendly incentives


1. Dasgupta (2021). The economics of biodiversity: the Dasgupta review: full report. (London, HM Treasury). ISBN:978-1-911680-29-1
2. Huber & Finger (2020). A Meta analysis of the Willingness to Pay for Cultural Services from Grasslands in Europe. Journal of Agricultural Economics. doi:10.1111/1477-9552.12361
3. Dallimer et al. (2020). Taking stock of the empirical evidence on the insurance value of ecosystems. Ecological Economics. doi:10.1016/j.ecolecon.2019.106451
4. Quaas et al. (2019). Insurance value of natural capital. Ecological Economics. doi:10.1016/j.ecolecon.2019.106388
5. Faith (2021). Valuation and Appreciation of Biodiversity: The "Maintenance of Options" Provided by the Variety of Life. Frontiers in Ecology and Evolution. doi:10.3389/fevo.2021.635670
6. Bartkowski (2017). Are diverse ecosystems more valuable? Economic value of biodiversity as result of uncertainty and spatial interactions in ecosystem service provision. Ecosystem Services. doi:10.1016/j.ecoser.2017.02.023
7. Drupp et al. (2018). Economic Inequality and the Value of Nature. Ecological Economics. doi:10.1016/j.ecolecon.2018.03.029
8. UN (2022). System of Environmental-Economic Accounting - Ecosystem Accounting. (https://seea.un.org/sites/seea.un.org/files/documents/EA/seea_ea_white_cover_final.pdf) Last accessed on: 5.2.22
9. DESTATIS (Statistisches Bundesamt, 2022). Environmental-economic accounting - Ecosystem Accounts. (https://www.destatis.de/EN/Themes/Society-Environment/Environment/Environmental-Economic-Accounting/ecosystem-account/_node.html) Last accessed on: 5.2.22
10. Isbell et al. (2013). Nutrient enrichment, biodiversity loss, and consequent declines in ecosystem productivity. Proc Natl Acad Sci USA. doi:10.1073/pnas.1310880110
11. Franzo (2021). Can Fixing Dinner Fix the Planet? (Baltimore, John Hopkins University Press). ISBN: 978-1-4214-4112-2
12. IPCC (2021). Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. (Cambridge, Cambridge University Press. In Press)
13. Kastner et al. (2021). Global agricultural trade and land system sustainability: Implications for ecosystem carbon storage, biodiversity, and human nutrition. One Earth. doi:10.1016/j.oneear.2021.09.006
14. OECD (2020). A Comprehensive Overview of Global Biodiversity Finance. (https://www.oecd.org/environment/resources/biodiversity/report-a-comprehensive-overview-of-global-biodiversity-finance.pdf) Last accessed on: 14.2.22
15. USDA ERS (2022). Conservation Programs. (https://www.ers.usda.gov/topics/natural-resources-environment/conservation-programs/) Last accessed on: 5.2.22
16. Lakner et al. (2020). Combining management plans and payment schemes for targeted grassland conservation within the Habitats Directive in Saxony, Eastern Germany. Land Use Policy. doi:10.1016/j.landusepol.2020.104642
17. Pe'er et al. (2019). A greener path for the EU Common Agricultural Policy. Science. doi:10.1126/science.aax3146
18. Pe'er et al. (2017). Adding Some Green to the Greening: Improving the EU's Ecological Focus Areas for Biodiversity and Farmers. Conservation Letters. doi:10.1111/conl.12333
19. Wiedmann & Lenzen (2018). Environmental and social footprints of international trade. Nature Geosci. doi:10.1038/s41561-018-0113-9
20. Koslowski et al. (2020). Quantifying Europe's biodiversity footprints and the role of urbanization and income. Glob. Sustain. doi:10.1017/sus.2019.23
21. Kling et al. (2012). From Exxon to BP: Has Some Number Become Better Than No Number? Journal of Economic Perspectives. doi:10.1257/jep.26.4.3
22. Groom & Turk (2021). Reflections on the Dasgupta Review on the Economics of Biodiversity. Environ Resource Econ. doi:10.1007/s10640-021-00560-2
23. OECD (2019). Biodiversity: Finance and the Economic and Business Case for Action. (https://www.oecd.org/env/resources/biodiversity/biodiversity-finance-and-the-economic-and-business-case-for-action.htm). Last accessed on: 14.2.22
24. Portfolio Earth (2021). Bankrolling Extinction: The banking sector's role in the global biodiversity crisis. (https://portfolio.earth/). Last accessed on: 15.2.22

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